Review of Passenger Transport Demand Elasticities

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Executive Summary

Introduction

This report was prepared in 2002 to assess international (including New Zealand) evidence on elasticities of demand for passenger transport (both public and private), and to recommend elasticity values that could be applied in forecasting the impacts on travel demand of urban transport policy measures in New Zealand.

Travel demand forecasting is concerned with predicting the response of travel demand (by mode, route etc.) to changes in one or more demand 'drivers' (i.e. costs, travel times, service levels). While elasticities are not precise predictive measures, they provide a relatively simple means by which such prediction can be undertaken, and they have the advantage that they are based directly on empirical evidence of demand responses in comparable situations.

The project covered research into elasticity values relating to the following:

- Effects of changes in **public** transport system variables (principally fares, service levels, in-vehicle time) on **public** transport demand;
- Effects of changes in **private** transport system variables (principally fuel prices, other vehicle operating costs, parking charges, toll charges) on:
  - **private** transport (car) demand,
  - **public** transport demand.

Travel demand elasticities are defined as the proportionate change in travel demand divided by the proportionate change in the relevant measure of supply, e.g. a typical fares elasticity value is –0.4, which implies that 10% increase in fares would result in a 4% decrease in demand.

Effects of changes that involve the **same mode** in both supply and demand may be represented through **direct elasticities**; while effects that involve **cross-modal** impacts may be represented though **cross-elasticity** measures, or through **a direct elasticity and a diversion rate.**

The research addressed variations in direct elasticity values, cross-elasticity values and diversion rates reflecting:

- Time scale of effects ('long run' versus 'short run');
- Initial level of variable (e.g. high fares versus low fares);
- Magnitude and direction of change in variable;
- Market segment and trip characteristics:
  - trip purpose, trip timing (peak versus off-peak versus weekend), trip length;
  - city size, area (CBD, non-CBD, suburban, etc.).

Literature Review

The project involved a comprehensive review of the relevant elasticity evidence available worldwide, but with a particular emphasis on New Zealand and Australian sources. This review covered the following aspects:

- Effects on public transport demand of changes in public transport variables, i.e. public transport fares; service levels; in-vehicle time; reliability; generalised costs (Appendices A – E).

- Effects on private car and public transport demand of changes in private transport variables, i.e. fuel prices; vehicle operating costs; parking charges; toll charges; in-vehicle time; generalised costs (Appendices F – K).

The references cited in these appendices are contained in the extensive Bibliography, which completes the Literature Review.

Recommendations

Public Transport Direct Effects

To assess the effects of changes in public transport variables on public transport travel demand, the set of short-run direct elasticity values (best estimates and typical range) shown in Table 1 for individual trip attributes is recommended.

Long-run elasticity values are about twice the corresponding short-run estimates, for all these variables.

The report also addresses elasticities for other trip variables (principally service reliability). It also comments on the variations in elasticities across different market segments, including variations by trip purpose, trip distance, city size, initial magnitude of variable (e.g. fare level, frequency), direction of change (increase or decrease) and magnitude of change.

In applying elasticities to estimate demand changes, an alternative to the 'individual elasticity' approach most commonly adopted is the generalised cost (GC) approach. This involves combining individual trip components into a single aggregated valuation (the generalised cost); and then applying a 'generalised cost' elasticity to the changes in this aggregated cost, reflecting changes in the individual trip component values. For this purpose, a typical average generalised cost elasticity value in the short-run is about –1.0.

This alternative approach has considerable merits in assessing the effects of urban transport policy measures, as it considers all trip components in a consistent manner across a range of circumstances (e.g. low or high fares, long or short trips).

Table 1 Summary of short-run public transport direct elasticity values.

Variable	Bus		Rail	
	Best Estimate	**Typical Range**	**Best Estimate**	**Typical Range**
Fares	–0.40	–0.20 to –0.60	–0.30	–0.20 to –0.50
Service Levels*	0.35	0.20 to 0.50	0.35	0.20 to 0.50
In-vehicle Time	–0.30	–0.10 to –0.50	–0.50	–0.30 to –0.70

* For medium-frequency services typical of NZ urban areas (at 20-30 minute frequencies).

Private Transport Direct Effects

To assess the effects of changes in private transport system variables on private transport (car) travel demand, the set of direct elasticity values (short-run and long-run, best estimate and range) shown in Table 2 for individual trip attributes is recommended.

The body of the report provides further comments on how these typical values vary across different market segments.

As for the public transport direct effects, there are merits in applying a 'generalised cost' elasticity approach in preference to the individual component approach. Typical generalised cost elasticities with respect to the variable costs of car travel are around –0.6 in the short run, and around –1.0 in the long run.

Table 2 Summary of private transport direct elasticity values.

Variable	Short run		Long run	
	Best Estimate	Typical Range	Best Estimate	Typical Range
Fuel prices	–0.15	–0.10 to –0.20	–0.25	–0.20 to –0.30
In-vehicle time	–0.30	–0.15 to –0.50	–0.60	–0.60 to –0.80
Parking charges (1)	–0.30	–0.10 to –0.60	N/A	N/A
Toll charges	–0.15	–0.05 to –0.40	N/A	N/A

N/A not available

(1) Relates to CBD commuter travel

Private Transport Cross-Modal Effects

Two approaches to estimating cost-modal effects using elasticity values have been assessed:

- **Cross-elasticity approach,** i.e. applying an estimated cross-elasticity, representing the proportionate change in public transport use relative to the proportionate change in the relevant private transport (time or cost) variable.
- **Diversion rate approach**, multiplying two factors:
  - the direct elasticity of private transport demand with respect to the relevant private transport variable; and
  - the proportion of the change in private transport demand that switches to/from public transport (i.e. the 'diversion rate').

The cross-elasticity approach is not generally recommended, as cross-elasticity values are sensitive to the base mode shares in each particular situation, and therefore not readily transferable to other situations. The diversion rate approach rate is preferred as providing a firmer base for policy analysis.

Table 3 provides best estimates of relevant diversion rates (both short-run and long-run). These may also be broken down by market segment, as detailed in the main text.

Table 3 Summary of recommendations for diversion rates.

Variable	Recommended Diversion Rate (best estimates)
Fuel Price Vehicle Operating Costs	30%
Toll Charges	c. 40%
Parking Charges	Regional CBD, work trips: 75% Regional CBD, non-work trips } 50% Suburban CBD, work trips } 50% Other: not defined
In-vehicle Time	20%

Priorities for Future Elasticity Research

While the relevant international elasticity literature is extensive overall, it is somewhat weak in a number of aspects (and in particular in regard to New Zealand and Australian evidence). Specific aspects within the scope of the review where better information would be particularly desirable include:

- Variations in elasticities over time from the initial change – short- v medium- v long-run effects;
- Differences in elasticities (both direct and cross-modal) between rail-based and bus-based modes;
- Difference in elasticities according to the 'base' level of the variable and according to the magnitude of the change;
- Cross-modal 'diversion rates';
- Transferability of elasticity values (on a suitably disaggregated basis) between countries;
- Long-run trends in elasticity values over time (i.e. is the public transport market becoming more or less elastic?).

Abstract

The report was prepared in 2002 to assess international evidence on elasticities of demand for passenger transport (both public and private) and to recommend elasticity values that could be applied in forecasting the impacts on travel demand of urban transport policy measures in New Zealand. While considerable information is available, both in New Zealand and internationally, on passenger transport demand elasticities, no comprehensive guide exists on appropriate values for use in New Zealand. The project was designed to fill this gap.

The research included a review of the international literature on passenger transport demand elasticities, relating to the following:

- Effects of changes in **public** transport system variables (principally fares, service levels, in-vehicle time) on **public** transport demand.
- Effects of changes in **private** transport system variables (principally in-vehicle travel time, fuel prices, parking charges, toll charges) on both **private** transport demand and **public** transport demand.

Recommendations for elasticity values applicable to urban areas of New Zealand are given.

1. Introduction

1.1 This Report

This report was prepared in 2002 to assess international evidence on elasticities of demand for passenger transport (which includes both public and private transport), and to recommend elasticity values that could be applied for forecasting the impacts on travel demand of urban transport policy measures in New Zealand.

1.2 Project Objectives and Scope

The overall objective of the project was to compile and assess information available, both locally and internationally, on passenger transport demand elasticities and thereby produce elasticities and cross-elasticities applicable to New Zealand conditions.

While considerable information is available, both in New Zealand and internationally, on passenger transport demand elasticities, no comprehensive guide exists on appropriate values for use in New Zealand conditions. The project was designed to fill this gap.

Demand elasticities assist in the assessment of the effects on public transport patronage of a wide range of both 'carrot' and 'stick' policy measures. They cover changes of the following types:

'Carrot' measures (i.e. directly impacting on the public transport system):
- Fares,
- Service levels,
- Travel time.

'Stick' measures (i.e. directly impacting on private (car) travel, hence indirectly impacting on public transport use):
- Fuel prices,
- Car parking charges,
- Road toll charges.

In the case of 'carrot' measures, only the direct elasticities are covered, i.e. the impact of changes in a public transport system variable on public transport demand. In the case of 'stick' measures, both the direct elasticities and the cross-elasticities are covered, i.e. the impact of a change in a private transport (car) system variable on both private transport demand and public transport demand (Table 1.1).

Demand elasticities differ according to the time scale being considered, the characteristics of the travellers, and other factors relating to the trip concerned. To the extent that data were available, the report includes variations in elasticity values reflecting:

- Time scale considered ('long run' versus 'short run');
- Initial level of variable (e.g. high fares versus low fares);
- Magnitude and direction of change in variable;
- Market segment and trip characteristics, e.g:
  - trip purpose,
  - trip timing (peak versus off-peak versus weekend),
  - trip length,
  - area (CBD, non-CBD, suburban, etc.),
  - city size.

Table 1.1 Scope of analysis for passenger transport demands.

Appendix No.	Variable	Impacts on (1) :	
		Public Transport Demand	**Private Transport Demand**
	Public Transport Variables	*Direct*	
A	Fares	◆ (27/12)	
B	Service Levels	◆ (11/10)	
C	In-vehicle Time	◆ (8/-)	
D	Reliability	◆ (-/-)	
E	Generalised Costs	◆ (-/-)	
	Private Transport Variables	*Cross-modal*	*Direct*
F	Fuel Prices	◆ (4/2)	◆ (6/-)
G	Vehicle Operating Costs	◆ (3/1)	◆ (4/-)
H	Toll Charges	◆ (-/-)	◆ (5/-)
I	Parking Charges	◆ (3/-)	◆ (6/-)
J	In-vehicle Time	◆ (5/-)	◆ (5/-)
K	Generalised Costs	◆ (-/-)	◆ (-/0-)

Notes: (1) Numbers in brackets relate to number of separate Australasian studies identified for elasticity values (Australia/NZ). Often individual studies include several values. Refer to Section 3.3.

The project involved a comprehensive review of the relevant evidence available worldwide. This included close liaison with a major UK research project (under the leadership of the UK Transport Research Laboratory) in which the key publication, *The Demand for Public Transport* (TRRL 1980), has been updated, and is now published (Balcombe et al. 2004). The work particularly focused on drawing together and reviewing all available New Zealand and Australian evidence on the topic, as such evidence was considered to provide the best guide to determine the appropriate elasticity values that could be adopted for New Zealand.

Inevitably, the report depends on the quality and quantity of the data available from previous international research. Some demand elasticity aspects (e.g. public transport fares elasticity) have been well researched and have an extensive literature, including a range of market segments and situations. Other aspects, particularly the cross-elasticity effects, have much more limited evidence and, in some cases, almost no evidence by market segment.

1.3 Report Structure

The remainder of this report is structured as follows:
Chapter 2 – Elasticity Concepts and Measures
Chapter 3 – Overview of the Literature
Chapter 4 – Public Transport Direct Effects
Chapter 5 – Private Transport Direct and Cross-Modal Effects

The full details of our international literature review are presented in a series of appendices (A to K), each covering a single variable (as indicated in Table 1.1). The main findings from the international review are summarised in Chapter 4 (public transport variables) and Chapter 5 (private transport variables).

2. Elasticity Concepts, Measures and Issues

2.1 The Elasticity Concept

The essence of travel demand modelling is to predict the response of travel demand to a change in one of the demand drivers (e.g. price, service levels, travel time, etc.). Elasticities provide a relatively simple means by which this can be undertaken.

Elasticity is a theoretically straightforward concept. It is defined as the ratio of the proportionate change in demand to the proportionate change in any factor which causes that change in demand. For example, a price elasticity of –0.30 indicates that, for a 1% increase (or decrease) in the price of a good, there is a 0.3% decrease (or increase) in the demand for that good or service. The negative sign signifies an inverse relationship between price and demand, i.e. the effect operates in the opposite direction from the cause.

If a 1% change in a parameter causes a greater than 1% change in demand, demand is often said to be 'elastic'. Conversely, if a 1% change in a parameter causes a less than 1% change in demand, then demand is said to be 'inelastic'. Most urban transport system changes elicit responses that are 'inelastic'.

Elasticities provide a practical method for quickly preparing first-cut, aggregate response estimates for a wide range of impacts, including traveller response to changes in the overall amount of service, fare levels, vehicular toll charges, parking charges, and fuel costs.

However, elasticities are not precise predictive measures and the values used in any particular application should be checked for the appropriate time-frame, competitive environment and urban development. Experience has shown that, when properly used, they indicate, reliably and quickly, the likely order of magnitude of response to system change, but their inherent range of error should always be allowed for when interpreting the results.

2.2 Elasticity Measures

Although applications often refer to the 'elasticity', three different measures of elasticity (discussed in detail in Appendix L) are commonly calculated and reported:

1. **Point elasticity** represents the elasticity associated with a very small change in the variable under consideration, and in theory is only valid for the particular point for which it is calculated. It cannot be estimated directly from observed data (except under very restrictive assumptions), but must instead be derived from an analytical-demand function estimated from observed data.

2. **Arc elasticity** calculates the 'average' elasticity over the range of any particular change. Since elasticities are not necessarily constant as demand changes, the

arc elasticity at any particular point will vary depending on the size of the change that is being considered.

3. **Shrinkage ratio** is the measure most commonly used, particularly by public transport operators. It relates the change in demand to the pre-change values of demand and the variable in question. This measure is simple in concept and easy to calculate but in theory will, like the arc elasticity, vary continuously and is strictly only applicable for the change from which it was observed.

In practice, the terminology associated with elasticities is not clearly defined in the literature, and without going back to the original calculations, it is unclear in many studies which definition has been applied. There is a growing use of arc elasticities as the preferred approach for use with quasi-experimental data, and this review has used them wherever they are available.

However, not too much should be made of these differences in definition. The variation in the results produced by the different concepts for small changes (say 10-20%) in the different independent variables is well within the normal margin of estimation error, and can be disregarded for practical purposes. Although more care needs to be taken when large changes (say 100%) are being considered, analysing such changes using elasticities can, in any case, provide only order-of-magnitude estimates.

2.3 Methods of Estimation

The two main methods of estimating demand elasticities, with the choice governed by data availability, the objective of the analysis, and time and cost constraints, are:

1. **Revealed Preference** (RP): data on observed behaviour revealing choices that have actually been made by travellers; and
2. **Stated Preference** (SP): data based on the stated behaviour of survey respondents when offered a hypothetical set of travel alternatives by the researcher.

2.3.1 Revealed Preference (RP)

The four main types of RP data, each with a related method of data analysis, are Time Series Analysis, Cross-sectional Analysis, Panel Data, and Before & After Studies.

2.3.1.1 *Time Series Analysis*

Time series analysis estimates the relationship between a dependent variable (e.g. public transport travel demand) and one or more explanatory (or independent) variables (e.g. price, service levels, fuel prices, etc.), using data collected for each variable over a number of time periods.

The simplest (and most common) time series approach assumes the dependent variable will completely adjust to any change in the explanatory variables within the same time period in which the change takes place. More sophisticated analyses use 'lagged' models, in which the dependent variable is expressed as a function of explanatory variables in both the current and previous time periods. These are better able to capture any long-run effects from changes in the explanatory variables. Temporary or permanent shifts in the dependent variable as a result of a factor outside the model (such as the impact of sporting events on public transport use) need to be accounted for, using dummy variables to ensure such shifts are not incorrectly attributed to the other dependent variables.

While all relevant variables should be included in the analysis, explanatory variables based on aggregate data often move together (e.g. GDP and elapsed time), causing multi-collinearity and the confounding of effects. Because of this, some models are estimated using annual changes in each variable. Although such models are less prone to correlation of the independent variables, they bring their own difficulties and are prone to auto-correlation (i.e. reductions in traffic because of random events will be automatically followed by increases as demand returns to 'normal' and vice versa).

2.3.1.2 *Cross-sectional Analysis*

As with time series analysis, cross-sectional analysis determines the relationship between a variable of interest and a number of explanatory variables, but it uses data from a single point in time obtained from a range of different locations (e.g. public transport use, fare levels and service levels from a series of different cities). Other cross-sectional models use data on individuals, allowing for different prices, incomes and other controlling factors, to estimate parameters for discrete choice models.

Problems arise with cross-sectional models when spatial and socio-economic differences are not explicitly included in the model, or are confounded (e.g. with higher-income people living in outer suburbs and lower-income in inner suburbs or vice versa), and causation is incorrectly attributed to differences in the independent variable set.

Pooled cross-sectional and time series data sets may also be used (where they are available), allowing greater freedom to estimate more complex model structures than is possible with either of the data sets alone.

2.3.1.3 *Panel Data*

Panel data is cross-sectional disaggregate data collected over a period of time from the same group of users, with the aim of eliminating variations in behaviour which are related to changes in socio-economic factors and personal preferences. This reduces the risk of attributing changes in observed behaviour over time to changes in the transport network, for example when they are actually related to variations in the socio-economic characteristics of the sampled population. However, the usefulness of panel data to monitor transport behaviour is limited in many countries because of the relatively high residential and employment mobility.

2.3.1.4 *Before and After Studies*

These models typically examine demand at a detailed level before and after a change. This type of study is often used to evaluate a change in demand caused by a one-off significant change in fares or service levels, and the models can be designed to meet any specific study requirements.

In practice, problems often occur because of the difficulty in accounting for other factors affecting demand between the 'before' and 'after' periods (e.g. weather), although these may be at least partially overcome through the use of control groups. Other disadvantages include the possibility of sample bias, and the difficulty in properly allowing for long-term lagged effects.

2.3.2 Stated Preference (SP)

Stated Preference (SP) methods, a form of quantitative market research, have been developed over the last 20 years to address the limitations of RP analyses. Because most RP analyses rely on aggregate data (e.g. from ticket sales), one issue is the difficulty of obtaining estimates disaggregated by key factors such as socio-economic characteristics that are not routinely available from operators. Another issue is that RP methods can only derive elasticities for the types of changes made in the past: they generally cannot address issues such as changes in the quality of service and the introduction of modes with new characteristics.

SP experiments typically offer each of a group of respondents a number of alternatives involving variations in some of the attributes (e.g. fares, journey time, service frequency) of a journey. Other aspects of service quality remain unchanged and respondents are asked to choose (or 'state') their preference between the alternatives presented. The method of analysis uses similar statistical methods to those used for analysing RP data.

The major weakness of SP estimates is that respondents may or may not behave in practice as they say they will in the experiments. This is related to problems of perception, e.g. SP can report how passengers claim they will behave if they perceive that service frequency has doubled; but if current perceptions of service frequency differ from objective measures, then very different results may ensue when service frequencies actually change. Similar problems arise when new modes are investigated. Care must be taken when applying SP elasticity values in isolation: as experience has shown that respondents typically overstate their response to alternative scenarios, and thus SP elasticity values are often significantly higher than the corresponding RP values obtained from observed data. Where possible, outputs from SP experiments should be combined with elasticity values (e.g. for fares) derived from RP data, effectively using the RP values to 'anchor' the SP results.

2.3.3 Summary of RP and SP Methods

While each method of estimation has its practical advantages and disadvantages, experience also shows that the choice of methodology influences the estimate itself. RP before-and-after studies and time-series analyses tend to produce the lowest values. RP cross-sectional modelling using generalised costs (Section 2.7) usually produces higher values, while SP studies tend to produce the largest values.

Given the documented problems in the interpretation of elasticity values derived through SP studies, this review primarily focuses on elasticities derived from RP data wherever these are available.

2.4 Factors Influencing Elasticity Values

2.4.1 Overview of Factors

No single elasticity value exists that can be uniformly applied in all situations, even within a given city, for any of the variables of interest.

Elasticity values are influenced by:

- Importance of the attribute in the total journey. Elasticities tend to be higher for attributes that account for higher proportions of the total 'generalised cost' of the trip (Section 2.7 of this report).
- Strength of competition. Elasticities tend to be higher where close substitutes exist for the mode in question.
- Opportunities for new trip generation/suppression and redistribution. Elasticities tend to be higher where a particular mode/route has a relatively small base mode share, as the growth potential is greater.
- Passenger characteristics. Some passenger groups may be more sensitive to price changes (e.g. pensioners, less well-off), others more sensitive to time changes (e.g. full-time workers).
- Trip characteristics. Off-peak/non-work trips are generally more elastic than peak/work trips. Elasticities also tend to vary with trip length, in part according to the substitutes available and their closeness of substitutability.
- Types of service (e.g. bus versus train, express versus all stops). Again much of the variation will be influenced by the alternatives available.
- Type and magnitude of the change in the independent variable, e.g.
  - large versus small changes;
  - increases versus decreases in price/quality.
- Time scale over which effects are measured (discussed further in Section 2.4.2).

All these factors need to be taken into account in considering the transferability of any elasticity estimates. To the extent possible using the available data, our literature review (Appendices A-K) has noted the factors present for each study reviewed, and the conclusions have been formulated taking them into account.

2.4.2 Time Scale of Effects

Research over the last 10 years in particular has highlighted that responses to price and service changes are not all 'instantaneous' but generally occur progressively over an extended time period. The weight of international evidence indicates that, for most variables, elasticities over the longer term are 1.5 to 3.0 times greater than the short-term responses (within the first 6-12 months). The time scale being considered is of substantial importance both in reviewing elasticities derived in other studies and in applying elasticities for particular purposes; and both short-run and long-run effects are likely to be of interest to analysts and policy makers.

In the literature review, the time scale to which the elasticities relate has been identified wherever possible, and categorised into one of the following three time bands:

- Short Run (SR) – effects occur typically within 6-12 months of change;
- Medium Run (MR) – effects within 2 to 7 years, typically after about 5 years;
- Long Run (LR) – effects after 8 years or more, and typically 10 to 12 years.

In many (perhaps most) studies reviewed, the authors have not been explicit about the time scale to which the elasticity estimates relate. In the absence of information to the contrary, our interpretation of appropriate time scales have generally been based on the following:

- Before and after analyses – short run;
- Time series, unlagged – short run;
- Time series, lagged – medium or long run;
- Cross-sectional analysis – long run.

2.5 Direct Effects and Cross-Modal Effects

As summarised in Table 1.1, the project is concerned with:

(A) effects of changes in the **public** transport system on **public** transport demand,

(B) effects of changes in the **private** transport system on **private** transport demand,

(C) effects of changes in the **private** transport system on **public** transport demand.

Effects (A) and (B) involve the same mode on both the supply side and the demand side. They may be represented through **direct** (own mode) **elasticities** (Section 2.5.1).

Effect (C) involves cross-modal impacts. These may be represented through a **cross-elasticity** measure, or through a direct elasticity measure and a '**diversion rate**', as described in Section 2.5.2.

2.5.1 Direct Effects

The direct effects (types (A) and (B) above) relate to the following variables (as listed in Table 1.1):

(A) The effects on public transport demand of changes in public transport variables:
  - fares
  - service levels
  - in-vehicle time
  - reliability
  - generalised costs.

(B) The effects on private transport demand of changes in private transport variables:
  - fuel prices
  - other vehicle operating costs
  - toll charges
  - parking charges
  - in-vehicle time
  - generalised costs.

These effects may be all measured through direct (single-mode) elasticities, e.g. the elasticity of public transport demand with respect to fare levels.

2.5.2 Cross-Modal Effects

The effects of changes in the supply (or price) of one mode on the use of another mode may be captured through the **cross-elasticity**. For example, if public transport demand increases 3% when the price of petrol increases by 10%, then the cross-elasticity of public transport demand with respect to petrol price is 0.3.

Cross-elasticities are related to direct elasticities by:

$$e_{rt} = -e_r D_r (m_r/m_t)$$

where:

e_{rt} = cross-elasticity of demand for public transport *(t)* with respect to private vehicle *(r)* price, etc.;

e_r = direct elasticity of demand for private vehicle trips with respect to private vehicle *(r)* price, etc.;

D_r = proportion of deterred private transport trips that switch to public transport ('diversion rate');

m_r = modal share for private transport *(r)*;

m_t = modal share for public transport (t).

As an example, assume:

e_r = –0.2 (e.g. direct elasticity of car travel with respect to petrol price);

D_r = 0.5 (i.e. 50% of diverted car trips switch to public transport);

m_r/m_t = 3 (i.e. modal shares are 75% private: 25% public).

The cross-elasticity of public transport demand with regard to petrol prices is then:

$$e_{rt} = 0.2 * 0.5 * 3 = 0.3$$

i.e. a 10% increase in petrol prices will result in a 3% increase in public transport use.

Compared with direct elasticities, cross-elasticities are:

- generally more difficult to measure;
- sensitive to the 'base' market shares of the two modes (as noted above); and
- thus not as readily transferable between different cities and situations.

Given these deficiencies, when reviewing the literature on cross-modal effects and its potential application and transferability, diversion rates have been derived from the literature and applied along with modal share and direct elasticities using the formula above. A wealth of evidence indicates that cross-elasticities are not readily transferable between situations (primarily because of differences in relative modal shares), but that both direct elasticities and diversion rates are relatively stable and more readily transferable.

The literature review for cross-modal effects has, wherever possible, covered data on diversion rates, as well as data on cross-elasticities. Unfortunately the data available on cross-elasticities are rather sparse on many aspects, and the data on diversion rates even more so. Our review of the evidence on cross-modal effects (i.e. demand for public transport with respect to changes in private transport variables) and our conclusions are summarised in Chapter 4 of this report.

2.6 Total Market and Sub-Markets

The interpretation of elasticity estimates needs a clear understanding of their scope. For example, if the service level on a bus route is improved, the extra passengers attracted may have switched from:

- other (parallel) bus routes;
- other public transport (non-bus) modes;
- private transport modes (car, walking, cycling);
- travel to other destinations;
- generation of entirely new trips.

Elasticity values may reflect some or all of these responses. Some key issues arising in interpretation of empirical estimates are discussed in Sections 2.6.1–2.6.3 of this report.

2.6.1 Public Transport Routes

One of the main responses to improvement of services on a single bus route may be the transfer of passengers from other parallel routes. The importance of this factor will depend on the extent to which parallel routes are close substitutes for the route in question.

Elasticity studies often quote only the patronage effect on the improved route, rather than the net effect on bus patronage overall. Such route-based elasticities are not transferable to other situations (where the degree of substitutability may be very different), and the literature review has given very limited weight to any route-based estimates.

2.6.2 Public Transport Modes

Similarly, an improvement to one public transport mode (e.g. bus) may result in significant transfers from an alternative public transport mode (e.g. train). As above, elasticities based on the single-mode effect are not readily transferable to other situations. The literature review has, wherever possible, been focused on elasticities relating to total public transport demand over all modes.

The literature sometimes refers to **conditional** and **own mode** elasticities, particularly in cases where public transport fares are changed. The conditional elasticity represents the responsiveness of demand if all public transport fares rise in line with each other, in which case switching between modes (or ticket types) would not be expected. The own mode elasticity represents the responsiveness when fares rise only for the mode in question. Again this response is dependent on the substitutability between the modes, and therefore it is not readily transferable.

2.6.3 Mode Choice Elasticities

Mode choice elasticities are concerned only with mode switching, and ignore any destination changes or trip generation/suppression. They are typically derived from mode choice models (which may include SP-based models) and from empirical studies that examine the split of a fixed demand volume between modes.

Mode choice elasticities are often quoted in the literature, and have been noted in our literature review. However, they understate the total market elasticity response, sometimes significantly so.

2.7 The Generalised Cost Approach

An alternative approach to estimating separate elasticities for each travel time and cost component is to apply the concept of 'generalised cost' (GC) (or 'generalised time' (GT)). GC is a measure composed of the monetary cost of a trip (such as public transport fare) plus other elements of journey time or disutility expressed in monetary terms (such as access and egress time, wait time, interchange and in-vehicle time). The approach assumes that the time for each component can be multiplied by an appropriate unit value of time to give an average cost equivalent for it. The cost components can then be added together, with the fare, to give a total GC for the trip. It is assumed that the level of demand can be expressed as a function of GC rather than in terms of the individual cost components. GT is the equivalent concept expressed in time (usually in minutes of in-vehicle time).

The GC for public transport is typically expressed as follows:

$$g = f + \alpha_1 t_1 + \alpha_2 t_2 + \alpha_3 t_3$$

where:

g = GC per trip;

f = fare per trip;

t_1, t_2, t_3 = time components (e.g. walking, waiting, in-vehicle);

$\alpha_1, \alpha_2, \alpha_3$ = corresponding unit value of time.

The responsiveness of the demand for travel to these variables can be estimated by applying an overall GC elasticity, rather than by applying the individual elasticities with respect to fares, in-vehicle time, etc.

This GC approach is often preferable as it gives more consistent results over a range of situations. The empirical evidence is that GC elasticities appear to be sensibly constant (for a given market) over a wide range of journeys with different component costs and elasticities; on the other hand individual component elasticities tend to vary according to the proportionate contribution of the component to the total generalised cost.

A simple relationship exists between each GC component and its corresponding elasticity in that the component elasticities are proportional to the contribution of that component to GC.

This is represented mathematically as:

$$e_g / g = e_f / f = e_1 / \alpha_1 t_1 = e_2 / \alpha_2 t_2, \text{ etc.}$$

Despite the convenience of using the GC approach for elasticity applications, direct empirical evidence on GC elasticities is limited. The literature review (Appendices A-K) reports on the evidence that we have been able to identify.

3. Overview of the Literature

3.1 International Literature

The study of urban transport demand elasticities internationally appears to have started in earnest in the 1970s, and by now empirical estimates have been derived from some thousands of individual studies. Of particular interest for this project are some key summary reviews, which have drawn together results from numerous individual studies and attempted to draw conclusions useful for policy purposes.

Internationally, these key review studies may be grouped into three 'waves', each about a decade apart.

3.1.1 Early 1980s

In this decade two major studies were carried out:

- The UK Transport and Road Research Laboratory (TRRL) co-ordinated an *International Collaborative Study of the Factors Affecting Public Transport Patronage*. Participants were primarily 'western' countries, from Europe, North America and included Australia and New Zealand. The study report (often known as the 'Black Book') was published in 1980 (TRRL 1980): it has served as a 'bible' on the subject for some 20 years.
- Over almost the same time period, the US Department of Transportation prepared a document of broadly similar scope, but focusing almost entirely on US empirical evidence. This was published in 1981 (Barton–Aschman Associates 1981).

3.1.2 Early 1990s

In 1992, two major elasticity review articles were published, through the Journal of Transport Economics and Policy:

- Goodwin (1992) – drew primarily on UK/European literature, included many unpublished sources, and focused on urban transport (car and public transport) elasticities. His article particularly addressed short-run and long-run elasticity effects.
- Oum et al. (1992) – drew primarily on North American sources, principally from academic journals, and with a wide coverage across both passenger (including inter-city and air travel) and freight transport.

3.1.3 Early 2000s

In this period, the focus has been on updating existing material:

- A comprehensive update of the 1980 'Black Book' has been undertaken, again co-ordinated by UK TRL. This update is now published (Balcombe et al. 2004) and has a primarily UK focus, without substantial involvement from other 'western' countries. However, our New Zealand research has liaised with the UK project team and has had access to its draft papers.

- As in the early 1980s, the US evidence is being progressively updated more-or-less in parallel with the UK work (Pratt et al. 2000, for TCRP).

3.2 Australasian Literature

In **Australia**, a number of individual studies undertaken in the 1970s and 1980s derived estimates of urban transport demand elasticities. These were brought together in a major review study in 1993 for the ARRB (Australian Road Research Board) (Luk & Hepburn 1993). This review aimed to derive elasticity values appropriate for the assessment of price-based travel demand management (TDM) initiatives in Australian cities. It summarised Australian evidence on urban transport price elasticities and compared these with Goodwin's (1992) findings that were largely based on UK and European data. In total, it identified 15 separate studies (mostly from the 1970s and 1980s) that had derived elasticity values relevant to the variables covered in this project (Table 1.1): 10 of these related to fares elasticities, the other 5 to direct and cross-elasticities for fuel price.

In comparing the Australian evidence with the average figures found by Goodwin, Luk & Hepburn commented that fuel price elasticities in Australia appeared to be less than Goodwin's averages; but that public transport fare elasticities appeared to be similar. However, while plausible, these conclusions should probably be regarded as indicative only, given the small number of Australian studies on which they were based.

A number of other review studies of Australian elasticity evidence have been undertaken over the last 10 years, some of which are widely available (e.g. Industry Commission 1994), but many of which comprise unpublished reports, often by consultants. In addition, the Australian Bureau of Transport and Regional Economics has compiled an extensive database of international elasticity estimates for all transport modes, both passenger and freight (BTRE 1999). However, the Luk & Hepburn review remains the most widely quoted source on Australian evidence.

In **New Zealand**, a review broadly comparable to that by Luk & Hepburn for Australia was carried out in 1990 (Travers Morgan 1990, Wallis & Yates 1990). This covered New Zealand sources of evidence on both direct and cross-elasticities for urban public transport. It identified eight separate New Zealand studies that had previously derived relevant elasticity values; and also undertook regression analyses on annual patronage in major centres to derive additional values.

3.3 Scope of Project Literature Review

Key features of this extensive literature review of urban transport demand elasticity estimates for each of the variables listed in Table 1.1, were as follows:

- The review covered evidence available internationally, but had a particular focus on capturing evidence from New Zealand and Australia.
- It covered evidence from the last 20 – 30 years.
- It made use of review articles wherever possible (for reasons of efficiency), but also covered original source articles where available.

- It co-ordinated closely with the UK (TRL) project (now published as Balcombe et al. 2004), so as to ensure access to more recent UK/European evidence.

The full literature review is presented in Appendices A to K of this report.

For each variable of interest, Table 1.1 includes figures on how many separate studies providing aggregate elasticity estimates were identified for Australia and for New Zealand (note that an individual study may provide several elasticity estimates). It is notable that:

- Many more studies (for Australia) could be identified than those reviewed by Luk & Hepburn (1993). To a large degree this is accounted for by new studies undertaken over the last 10 years, although many of these have not been made widely available.
- Of the total studies (112), over half were related to values for public transport fares (39) and service levels (21).
- For most other variables, very few relevant studies (up to only eight), particularly for New Zealand, are available. At a more disaggregate level, even fewer relevant Australasian studies are published.

Given the patchiness of the Australasian evidence, our approach has been to supplement the available values with values from international evidence in developing conclusions and recommendations on appropriate elasticity values for New Zealand. However, we have given relatively greater weight to the Australasian values, where these have been derived in a rigorous manner. It is notable that, for those variables (fares, service levels) for which considerable Australasian evidence exists, this evidence appears to be fully consistent with the weight of the international evidence. This gives some confidence that international values are generally reasonably transferable to the New Zealand–Australian situation.

4. Public Transport Direct Effects

4.1 Scope of Literature Review

The international and New Zealand literature was reviewed for evidence of the direct and cross-modal effects of eleven variables of interest which influence passenger transport demand modelling, grouped under either public or private passenger transport. The detailed material obtained from the review has been set out in Appendices A to K, for each of the variables listed in Table 1.1.

The literature concerning public transport was reviewed for evidence of the direct effects of five of these variables – Fares, Service levels, In-vehicle time, Reliability, Generalised costs. They are discussed in Appendices A-E respectively. Patronage responses are detailed for changes in the variables for public transport (bus, rail, and public transport generally), in the short run, medium run and long run.

Both aggregated and disaggregated values are considered. Other factors such as direction (i.e. increase/decrease) of the changes, base levels of the variables, and magnitude of the changes are covered as well. Australian and New Zealand literature has been considered separately from that of international origin.

4.2 Summary of Findings

4.2.1 Overall Elasticities

Table 4.1 summarises the range of **short-run** aggregate direct elasticity estimates obtained from the Literature Review (Appendices A-E) in relation to fares, service levels and in-vehicle time. Three points warranting particular comment are:

- Of the three variables covered in Table 4.1, the best evidence (both in quality and quantity) relates to fares, the next best to service levels, and the least and/or worst evidence to in-vehicle time.

- Much of the short-run service level elasticity evidence is derived from time series data. This will tend to over-estimate elasticity values because of cause and effect correlations, and should be treated with particular caution.

- From the evidence it is unclear whether the elasticities for rail-based services are systematically different from those for bus-based services, or whether the apparent differences are instead a function of the characteristics of the trips made on each mode (e.g. rail trips tend to be longer than bus trips and hence a higher in-vehicle time elasticity might be expected). While a common perception would be that rail is more attractive than bus as an alternative to the car, and therefore rail elasticities might be higher (particularly for service levels and in-vehicle time), there is no clear evidence that this is the case.

Table 4.1 focuses on short-run elasticities. For the **long run,** the evidence is generally consistent that elasticities are around twice those for the short run on all three variables, but with a reasonable range of between 1.5 times and 2.5 times the short run values.

Table 4.1 does not include elasticity values relating to service reliability, as little quantitative research is available on this aspect (despite its importance to users). Our conclusions on the two separate aspects of 'reliability' from the evidence that is available are:

- In the case of 'missed trips', the demand elasticity with respect to the change in vehicle kilometres would be 4 to 5 times that for a scheduled service adjustment: this gives an effective elasticity in the order of 1.5 to 2.0.
- In the general case of irregular services, the elasticity with respect to the standard deviation of arrival times is estimated at around twice the elasticity for in-vehicle time, i.e. in the range –0.6 to –1.0.

Table 4.1 Summary of short-run aggregate elasticity values.

Key Variable	Bus		Rail	
	Best Estimate	Typical Range	Best Estimate	Typical Range
Fares	–0.40	–0.20 to –0.60	–0.30	–0.20 to –0.50
Service Levels (1)	0.35	0.20 to 0.50	0.35	0.20 to 0.50
In-vehicle Time	–0.30	–0.10 to –0.50	–0.50	–0.30 to –0.70

(1) For medium-frequency services typical of NZ urban areas (at 20-30 minute frequencies).

4.2.2 Disaggregate Elasticities

Table 4.2 summarises the evidence on the variation of the three key elasticities (fares, service levels, in-vehicle time) across a range of trip characteristics. Some points worthy of particular comment are as follows:

- As noted in Section 4.2.1, the most or best evidence relates to fare elasticities, and the least or worst relates to in-vehicle time.
- Strong systematic variations in elasticities exist between trip purposes and time periods (the two factors being strongly correlated), for all three variables. Weekday off-peak elasticities are around twice peak period elasticities; and weekend elasticities are generally higher than weekday off-peak values.
- Elasticities vary in a complex way with trip distance: this can be explained in part by the availability of substitutes (high elasticities for short trips having the alternative of walking), and in part by the importance of the variable measure in the total trip generalised cost.
- Elasticities appear to vary systematically with city size, although the fare effect and the service level effect appear to be opposite (this aspect has rather limited data).

- Both fare elasticity and service elasticity appear to vary strongly, and more-or-less linearly, with the magnitude of the base fare or headway. This is particularly significant in regard to headways (or frequencies): a typical service elasticity would be 0.1 to 0.2 at high frequencies (better than every 10 minutes) increasing to around 0.5 to 0.6 or more at lower frequencies (in the order of hourly or longer). These variations are broadly consistent with a constant generalised cost elasticity formulation (see Section 4.3.2*)*.

- Most studies show no significant difference in elasticities between fare increases or decreases, and between large or small fare changes. Very little evidence is available about any differences relating to the direction of change (i.e. increase or decrease) for either service levels or in-vehicle time.

Table 4.2 Summary of evidence on disaggregate elasticities for key variables.

Aspect	**Elasticity Variable**		
	Fares	**Service Levels (1)**	**In-vehicle Time**
Time horizon	Long run typically double (range 1.5 to 3.0) short run.	Long run typically about double short run.	Very limited evidence: indicates long run 1.5 to 2.0 times short run.
Trip purpose/ time period	Off-peak/non-work typically twice peak/ work; weekend most elastic.	Off-peak/non-work typically c. twice peak/ work; weekend most elastic (may be partly frequency differences).	Inconclusive re relative elasticities; although most evidence is that off-peak is more elastic than peak.
Trip distance	Highest at very short distances (walk alternative); lowest at short/medium distances; then some increase and then decrease for longest distances (beyond urban area).	Highest at short distances (walk alternative).	Limited evidence – longest trips more elastic than short/medium distance trips.
City size	Lower in larger cities (over 1 million population) – US evidence.	Higher in larger cities – EU evidence.	No evidence.
Base level of variable	Elasticities broadly proportional to the base fare level (based on recent UK study, otherwise limited evidence).	Elasticities increase with headways (broadly proportional up to c. 60 mins headway).	No firm evidence – although expect elasticities to increase with proportion of total trip (generalised costs) spent in vehicle.
Magnitude of change	No significant variation in elasticities with magnitude of change (most studies).	No evidence.	No evidence.
Direction of change	No significant differences for fare increases and decreases (most studies).	No evidence.	No evidence.

US United States; UK United Kingdom; EU European Union

4.3 Recommendations

Two alternative approaches that might be recommended in applying elasticity values to assess the impacts of changes in public transport services, are:

- individual elasticity approach, and
- generalised cost approach.

4.3.1 Individual Elasticity Approach

This approach would apply separate elasticities to any change in fares, service levels, etc. For this purpose, use of the aggregate values given in Tables 4.1 and 4.2, and the associated commentary is recommended. Note in particular the need to:

- Determine whether short-run or long-run values are relevant for the application under consideration, and select appropriate values accordingly;
- Select service level elasticities appropriate to the base frequencies on the service being considered.

4.3.2 Generalised Cost Approach

As discussed in Section 2.7 of this report, one useful approach to applying elasticity values that provides consistent results over a wide range of situations is the 'generalised cost' (GC) formulation. Under this formulation all the individual trip components are combined into a single valuation known as the 'generalised cost' of the trip. Then a generalised cost elasticity is applied to reflect the effects of varying any trip component, according to its weighting in the overall generalised cost.

Table 4.3 provides an indicative valuation of a typical urban bus trip in terms of its various components – fares, service levels (access/egress, waiting time), and in-vehicle time – aggregating to the generalised cost. It shows that:

- Summing the component elasticities for the typical urban bus trip gives a total GC elasticity of (–)1.40: this is broadly consistent with direct evidence on GC elasticities (Appendix F), although somewhat on the high side.

- Taking this value and dividing it back between individual trip components in proportion to their component GCs, gives component elasticity values that are not very different from the initial estimates and certainly well within the range of figures estimated (Table 4.1).

- This indicates that the GC approach will give results, for a typical trip, that are generally consistent with using the component elasticities.

- Further, the GC formulation will behave in the 'right' way (consistent with the empirical evidence) if individual component costs differ, e.g. if the base fares were to double, the effective fares elasticity within a GC formulation would broadly double (assuming the total GC elasticity stays constant).

Therefore adopting the GC approach would have considerable merits for assessing the effects of changes in fares, service levels, etc. Based on the evidence in Appendix E (Public Transport Generalised Costs), the most appropriate GC average elasticity value is about –1.0 in the short run, i.e. rather lower than the synthesised estimate given in Table 4.3. This average value may be disaggregated by the different aspects given in Table 4.2, as appropriate.

Table 4.3 Generalised cost analysis for a typical urban bus trip.

Component	Typical Time (min)/ Cost (NZ$)	Generalised Cost (GC) (3) (NZ$)	%Total Generalised Costs (NZ$)	Typical GC Component Elasticity (4)	Effective Elasticity in GC Formulation (5)
Fare	$1.80	$1.80	24	–0.40	–0.34
Service Levels:					
Access/Egress (1)	10 min	10x2x0.1=$2.00	27	–0.35	–0.38
Waiting Time (2)	8 min	8x2x0.1=$1.60	22	–0.35	–0.31
In-vehicle Time	20 min	20x0.1=$2.00	27	–0.30	–0.38
Total		$7.40	100%	–1.40	–1.40

Notes:

(1) Allows for walk time at both ends of trip

(2) Corresponds approximately to a 20 minute frequency service

(3) Assumes:
– Value of time (in vehicle) = $0.10/minute ($6/hour)
– Access/egress and wait time valued at twice in-vehicle time

(4) Relates to bus (short run) values derived from observed data, from Table 4.1

(5) Pro rated according to GC elasticity x proportion of GC for component.

5. Private Transport Direct and Cross-Modal Effects

5.1 Scope of Literature Review

The international and New Zealand literature concerning private transport elasticities was reviewed for evidence of the direct and cross-modal effects of six of the eleven variables of interest which influence transport demand modelling. These private transport variables – Fuel prices, Vehicle operating costs, Toll charges, Parking charges, In-vehicle time, Generalised costs – are discussed in Appendices F-K respectively. The direct and cross-modal effects were reviewed separately for each variable, and the Australian and New Zealand literature has been considered separately from that of international origin.

5.2 Direct Effects – Summary of Findings

Table 5.1 summarises evidence (drawn from Appendices F-J) on the direct elasticities of private transport (car) demand with respect to the five private transport cost and time variables examined, i.e. fuel prices, vehicle operating costs, in-vehicle time, parking charges, toll charges. The table:

- summarises evidence on aggregate elasticities (short-run and long-run);
- summarises any available evidence on disaggregate elasticity values (e.g. peak v off-peak);
- provides additional notes and comments, including on the availability and quality of relevant evidence.

The quality and quantity of the available evidence differs considerably from variable to variable:

- The variable for which the best evidence is available is **fuel prices**, but even for this disaggregated evidence is limited.
- The evidence relating to overall **vehicle operating costs** is not extensive, and in most cases precisely what costs are included is unclear. Little weight is therefore given to this evidence in drawing useful conclusions and recommendations.
- For **in-vehicle time**, the quantity and quality of aggregate evidence is moderate, but disaggregated evidence is very limited.
- For **parking charges**, the quantity and quality of aggregate evidence is quite good, but mainly relates to mode-choice studies for CBD commuters, and to short-run values. Evidence for other market segments and situations is very limited.
- For **toll charges**, relevant evidence (for area-wide tolling schemes) is rather limited, but provides reasonably consistent, short-run, aggregate results. Again disaggregated evidence is extremely limited.

Table 5.1 Summary of direct elasticity evidence.

Variable	Aggregate Evidence	Disaggregate Evidence	Additional Notes
Fuel Prices	• Average short-run values –0.15 (typical range –0.10 to –0.20). • Average long-run values –0.25 (typical range –0.20 to –0.30).	• Off-peak/non-work values typically twice peak/work values; weekend values higher than weekday. • Little evidence on values for price decreases v increases.	• Extensive international evidence on effects of fuel price changes on fuel consumption, less on effects on traffic levels. • Evidence ambiguous as to whether long-run values exceed short-run values (in long-run, people may purchase more fuel-efficient cars, etc., thus less need for changes in travel habits).
Vehicle Operating Costs	• Average short-run values –0.20 (typical range –0.10 to –0.25). • Average long-run value –0.30 (typical range –0.20 to –0.40).	• Off-peak/non-work values typically 1.5 to 2.0 times peak values (rather limited evidence).	• In general this category includes both fixed and variable costs of motoring (including fuel). But many cases have a lack of clear definition of what costs are included in the assessments. • Also the relevant literature is not very extensive and often does not clarify whether estimates are long- or short-run. • For these reasons the reliability of estimates is questionable.
In-vehicle Time	• Average short-run values –0.30 (typical range –0.15 to –0.50). • Average long-run values –0.60 (typical range –0.30 to –0.80).	• Very limited evidence – inconclusive on relative values for peak/work v off-peak/non-work trips.	• Relevant literature is not very extensive, and mostly relates to mode choice or cross-sectional studies.
Parking Charges	• Typical values (short-run) are –0.30 (range –0.10 to -0.60), for CBD commuter trips. • No clear evidence on long-run values. • No clear evidence on non-CBD commuter or non-commuter trips (non-commuter trips likely to be relatively elastic, as alternative destinations are often available).	• Limited evidence indicates commuter elasticities lower for suburban destinations than CBD destinations (alternative modes are less attractive).	• Relatively few relevant studies on effects of area-wide parking pricing policies on car travel demand: most of these relate to CBD commuters and focus on mode-choice elasticities. Most relevant studies assumed to relate to short-run, although often unclear. • Many studies relate to parking demand at an individual site, so not directly relevant.
Toll Charges	• Typical values (short-run) are –0.15 (range –0.05 to -0.40). • No clear evidence on long-run values (likely to be greater than short-run, as for other variables).	• Very limited evidence – indicates peak and off-peak values similar.	• Relatively few studies of area-wide tolling or equivalent (where diversion to alternative routes is not a major effect). Most evidence appears to be short-run (before/after studies). • Expect considerable range of results as initial tolls will be very different in different situations.

In terms of the **aggregate** evidence, Table 5.2 provides an overview of our 'best estimate' values that are reasonably reliable:

- Long-run values (where available) are broadly twice short-run values: this is consistent with the public transport results (Chapter 4).
- The in-vehicle time elasticity is about twice the fuel price elasticity. This is consistent with the expected relative importance of the two variables in total trip (generalised) costs. (A typical fuel price of 10¢/km and average speed of 40km/h results in fuel costs of $4.00/h. This is broadly half the typical values of travel time savings for non-work travel.)
- The toll charge elasticity (short-run) is on a par with the fuel price elasticity. This suggests that the average level of tolls charged in the studies examined is similar in magnitude to petrol costs for the trips involved.

Table 5.2 Summary of best estimates for aggregate direct elasticities.

Variable	Best-estimate Elasticity	
	Short run	Long run
Fuel prices	–0.15	–0.25
In-vehicle time	–0.30	–0.60
Parking charges (1)	–0.30	N/A (2)
Toll charges	–0.15	N/A (2)

(1) Relates to CBD commuter travel

(2) N/A denotes not available

The **disaggregate** evidence available (Table 5.1) is surprisingly limited. Perhaps the main conclusion that can be drawn is that cost-related elasticity values for the weekday off-peak are around twice those for the peak, and are even higher at weekends. This is again consistent with the public transport results (Chapter 4).

5.3 Direct Effects – Recommendations

As for the public transport elasticities, two elasticity-based approaches that might be used in estimating the direct effects of changes in private (car) travel costs on travel demand are:

- individual elasticity approach, and
- generalised cost approach.

5.3.1 Individual Elasticity Approach

This approach would apply separate elasticities to any changes in the various time/cost components of the car trip. For this purpose we would recommend use of:

- The best estimate aggregate values given in Table 5.2 (short run and long run).
- The range of aggregate values given in Table 5.1 for purposes of sensitivity testing.
- The disaggregations given in Table 5.1 when particular market segments are being considered (to the extent that relevant evidence is available).

5.3.2 Generalised Cost Approach

As discussed in Section 2.7 and applied to public transport in Section 4.3.2 of this report, one useful approach to applying elasticity values that provides consistent results over a wide range of situations is the 'generalised cost' formulation. Under this formulation all the individual trip components are combined into a single valuation known as the 'generalised cost' of the trip. A generalised cost elasticity is then applied to reflect the effects of varying any trip component, according to its weighting in the overall generalised cost.

Examining the best estimates for component elasticities in Table 5.2, we note that:

- For a typical car trip, the 'marginal' generalised cost (i.e. excluding car purchase, fixed costs and perhaps maintenance), comprises mainly fuel and travel time. On this basis, the 'marginal' generalised cost elasticity would be about –0.45 in the short run, -0.85 in the long run.
- If an 'average' generalised cost approach were taken (i.e. including car purchase, fixed costs, etc.), total money costs would be around 4 to 5 times petrol costs. Including time costs this would result in an 'average' generalised cost elasticity of around –0.95 to –1.10 in the short run, –1.60 to –1.85 in the long run.
- For most purposes, the 'marginal' generalised cost elasticity values are probably the more relevant, as these contain the cost elements affected by decisions about individual trips.
- The range of generalised cost elasticity estimates derived from these analyses compares quite well with those drawn directly from other studies (Appendix K).

Based on the evidence above and these other studies, the following set of generalised cost elasticities is recommended for use in policy assessments:

- Short run: –0.6 on marginal costs;
  –1.2 on average costs (where appropriate).
- Long run: –1.0 on marginal costs;
  –2.0 on average costs (where appropriate).

Where needed, these values may be disaggregated based on the evidence given in Table 5.1.

5.4 Cross-Modal Effects – Summary of Findings

Table 5.3 presents our summary of the evidence (drawn from Appendices F-J) on the cross-modal effects on public transport demand of changes in the five private transport cost and time variables examined (fuel prices, vehicle operating costs, in-vehicle time, parking charges, toll charges). The table summarises the evidence under two headings:

- Cross-elasticity evidence (i.e. the proportionate change in public transport use relative to the proportionate change in the relevant cost or time variable).
- Diversion rate evidence (i.e. the proportion of 'deterred' car users who switch (divert) to public transport).

Table 5.3 Summary of cross-modal effects.

Variable	Cross-Elasticity Evidence	Diversion Rate Evidence
Fuel Prices	• Most aggregate values (SR) in range 0.07 to 0.30, with typical value c. 0.15. • Values significantly higher for peak than off-peak: NZ evidence is for peak value 2 to 3 times off-peak. • As expected, values tend to be higher where PT has low base mode share (e.g. US), lower where there is a high PT mode share (e.g. Europe). • Mixed evidence on LR v SR: reasonable grounds for expecting LR response may be lower than SR response, as scope for other adaptive behaviours.	• Typically c.30% of people deterred from car use by higher fuel prices switch to PT. • Proportion varies significantly by market segment and situation: – Peak trip proportion is twice or more off-peak proportion (e.g. London: peak c.50%, off-peak c.25%). – Long trip proportion higher than for short trips (where walking/cycling is competitive alternative). – Higher proportion where quality of PT alternative is higher (e.g. CBD trips v suburban trips).
Vehicle Operating Costs	• Wide range of evidence on aggregate figures: –Aust/NZ: most values in order of 0.1. –EU: very wide range of estimates (0.03 to 0.8) but with typical figures around 0.3 to 0.4. –US: few estimates, but appear higher than elsewhere (around 0.8). • No clear evidence on LR v SR values. • Limited evidence indicates peak values in the order of twice off-peak. • Mixed evidence on rail v bus values.	• No direct evidence available (would expect similar results as for fuel prices).
In-vehicle Time	• Most aggregate values in range 0.07 to 0.40, with typical value around 0.15 to 0.20. • Very limited evidence on LR v SR. • Limited evidence indicates peak/work values around twice off-peak/non-work values.	• No direct evidence available. • Prima facie, could expect lower diversion rates than for fuel prices (time-sensitive people less likely to switch to PT than cost-sensitive people).
Parking Charges	• Very limited evidence. • Elasticity estimates range from 0.02 to 0.30, but it is often unclear to what market segments they apply (e.g. CBD v non-CBD, work v non-work). • No evidence on LR v SR, or other segmentation differences.	• Very limited evidence. • Indications are for very high diversion rates for CBD work trips, lower for other purposes and destinations.
Toll Charges	• Very limited evidence, with values identified in the range 0.17 to 0.80. • Best evidence relates to the Singapore Area Licensing Scheme, but dubious whether this is transferable to NZ situation.	• Very limited evidence. • Most relevant evidence (Milan) found that c.40% of deterred car users switched to PT in response to peak period charging system.

LR – long run; SR – short run; PT – public transport; CBD – Central Business District

The quality and quantity of the evidence available is very limited at an **aggregate** level, particularly in relation to diversion rates. At a **disaggregate** level, the evidence is even more limited:

- The variable for which the best evidence is available is **fuel prices**, but even this is limited and results vary over a wide range.
- As for the direct effects, the evidence relating to **vehicle operating costs** (VOC) is quite limited, and in most cases it is unclear precisely what costs are included. Thus, little weight has been given to this evidence.
- For **in-vehicle time**, some cross-elasticity evidence exists but no diversion rate evidence.
- For **parking charges**, evidence is very limited, and often is unclear which market segments are covered.
- For **toll charges**, the evidence is again very limited and its relevance to the New Zealand situation is doubtful.

In terms of the evidence itself, the main conclusions that can be drawn on **cross-elasticities** are as follows:

- A wide range of aggregate values is evident from the literature.
- Typical aggregate cross-elasticity values for cost components (e.g. fuel prices, VOC) that might apply in the New Zealand situation are in the order of 0.1 to 0.3.
- Values tend to be higher in situations with a low public transport mode share (e.g. US), lower with a high mode share (e.g. EU countries). New Zealand/Australia would tend to be towards the middle of this spectrum.
- Evidence on long-run versus short-run values is inconclusive. (It can not necessarily be asserted that long-run values would be greater than short-run values, as in the case of direct elasticities.)
- Peak/work trip cross-elasticities tend to be in the order of twice off-peak/non-work values. (Note that this result is 'opposite' to that for direct public transport elasticities, where peak values are typically half off-peak values.)

In terms of **diversion rates**, the main conclusions are:

- For cost variables (e.g. fuel prices), the typical overall diversion rate is around 30%.
- Where cost impacts focus differentially on travellers to or from areas with a good public transport service (e.g. CBDs), diversion rates are higher than this overall figure.
- Diversion rates for peak period/work trips are around twice or more those for off-peak/non-work trips.
- Diversion rates for long trips are substantially higher than for short trips (where walking or cycling are competitive alternatives).
- No evidence has been identified on differences in diversion rates (or cross-elasticities) between drivers and passengers.

5.5 Cross-Modal Effects – Recommendations

As discussed in Chapter 2.5, diversion rates are recommended for estimating cross-modal effects because they provide a firmer base for policy analyses. Cross-elasticity values are not recommended because they are sensitive to the base mode shares in each particular situation. Table 5.4 summarises our recommendations in relation to diversion rates from private (car) to public transport in response to changes in car travel cost or time components.

The following comments may assist in interpretation of these recommendations:

- Diversion rates are sensitive to two main factors. The first of these is the 'competitiveness' of the public transport service offered relative to car travel: for example much higher diversion rates apply to CBD-oriented trips than to typical suburban trips.
- The second factor is trip purpose: work trips typically have diversion rates twice those for non-work trips. (In practice, the trip purpose/time period effect and the public transport service effect are difficult to separate.)
- Diversion rates for time components are believed to be lower than for cost components (although evidence is insufficient on this point).
- Long-run and short-run diversion rates are assumed to be similar (although again the evidence is inconclusive).
- Diversion rates are lower than average for shorter trips (where walking and cycling are competitive modes).

Table 5.4 Summary of recommendations for diversion rates.

Variable	Average Diversion Rate Recommendation	Estimates by Market Segment
Fuel Price/ Vehicle Operating Costs	30%	• Long v short run: inconclusive, assume equal • Time period/purpose: peak/work proportion approx. twice off-peak/non-work proportion • PT service quality: higher proportions where high level/ quality of PT service • Trip length: lower for short trips
Toll Charges	c. 40%	• Proportions depend on nature of scheme (all day v peak only, etc.) and location (primarily CBD trips, all trips, etc.) • For area-wide/all-day scheme, would expect same diversion rates as for fuel prices/VOC
Parking Charges	• Regional CBD, work trips: 75% • Regional CBD non-work trips and suburban CBD work trips: 50% • Other: not defined	
In-vehicle Time	20%	• As for fuel prices/VOC

6. Conclusions

The study has reviewed international evidence on passenger transport demand elasticities and recommended therefrom elasticity values that may be applied in forecasting the impacts on travel demand of urban transport policy measures that may be contemplated in New Zealand. It has covered:

- Direct elasticities for the effects of changes in:
  - public transport system variables on public transport demand; and
  - private transport system variables on private transport (car) demand.
- Cross-elasticities (and diversion rates) for the effects of changes in private transport system variables on public transport demand.

In terms of the direct effects associated with changes to the public and private transport systems, the study recommended:

- Short-run elasticity values (mean, range) for public transport travel, by bus and rail modes, for fares, service frequencies and in-vehicle time
- Short-run elasticity values (mean, range) for car travel, for fuel prices, in-vehicle time, parking charges and toll charges
- Factors to derive long-run values from short-run values
- A 'generalised cost' methodology and values, for use where appropriate
- Indicative variations in values according to key disaggregation factors (e.g. trip purpose/time period, trip distance).

For the cross-modal effects of changes in private transport system variables on public transport demand, the study recommended cross-modal 'diversion rates' with respect to fuel prices, toll charges, CBD parking charges and in-vehicle time.

While the international literature on urban travel demand elasticities is extensive, the evidence is still quite sparse on many aspects relevant for urban transport policy assessment. This conclusion is very much reinforced by the even sparser New Zealand and Australian sources.

7. Priorities for Future Elasticity Research

While the relevant international elasticity literature is extensive overall, it is somewhat weak in a number of aspects (and in particular in regard to New Zealand and Australian evidence). Specific issues within the scope of the review where better information would be highly desirable include:

- Variations in elasticities over time from the initial change – short- v medium- v long-run effects (and the pattern of 'ramp up');
- Differences in elasticities (both direct and cross-modal) between rail-based and bus-based modes;
- Difference in elasticities according to the 'base' level of the variable and according to the magnitude of the change;
- Cross-modal 'diversion rates';
- Transferability of elasticity values (on a suitably disaggregated basis) between countries;
- Long-run trends in elasticity values over time (i.e. is the public transport market becoming more or less elastic?).

Appendices

Appendix A: Public Transport Fares

A1. Introduction

This appendix is concerned with the literature detailing the effects of public transport fares on public transport/own mode use (i.e. the direct elasticity). The direct elasticity effect is particularly well researched in New Zealand, Australia and internationally. Evidence is categorised into that specific to bus, rail and to public transport in general. Tables A1 to A6 summarise the ranges of elasticities by these modes.

Notably, a wide range of observed elasticities exists which can be explained, in part, by a number of factors such as time horizon (i.e. short run, long run), public transport mode, time of day travel, trip purpose, country, and the size of the city/urban area. This appendix makes these distinctions (where possible) to help analyse passenger responses to fare changes.

A2. International Evidence

A2.1 Bus Fares

A2.1.1 Overall Estimates

Table A1 details the international evidence on bus patronage responses to fare changes. As noted in Chapter 2 of the report, there is an important distinction between short-run (SR) and long-run (LR) elasticities of demand. In the long run, passengers are better able to adjust to price signals than in the short run, and hence long-run demand tends to be more elastic than short-run demand. Unfortunately, few studies are explicit about the time horizon and often we have had to rely on the original author's interpretation of their results.

Short Run (SR)

The earlier influential reviews concluded that a reasonable 'rule and thumb' for a public transport fare elasticity internationally was –0.30, which supported the Simpson-Curtin formula of –0.33. This figure was widely acknowledged to be appropriate until the early 1990s. However, since that time there appears to have been a drift upwards to around –0.40. Several comprehensive international studies support this conclusion:

- APTA (1991) provided a comprehensive examination of fare elasticities for the bus transit mode based on analysis of 52 transit operators in the US. The results indicated an average value of –0.41.
- Balcombe et al. (2004) suggested an overall value of –0.41 in its review of evidence from the UK and internationally.
- Dargay & Hanly (1999) estimated a value of –0.40.
- In Europe, ISOTOPE (1996) estimated an average value of –0.42.
- Goodwin (1992) revealed slightly lower SR estimates that generally ranged from –0.21 to –0.37 based on a comprehensive review of international literature.

Goodwin also found that before and after studies produced an average SR value of –0.21, compared to an average value of –0.37 using unlagged time series data. However, other review studies show no clear evidence of any difference between the two methods.

Medium Run (MR)

The medium-run estimates were generally higher than the short-run values and tended to be of the order of –0.50. Balcombe et al. (2004) in that review reported values which were of the order of –0.5 to –0.6. However this was from two sources only and the authors urge caution when making assumptions. These values were very similar to those found by Goodwin (1992) and Halcrow Fox et al. (1993b).

Ass

Long Run (LR)

The international evidence generally suggested that LR elasticities are between 1.5 times greater and 3 times greater than SR estimates. Some of the major findings included:

- Dargay & Hanly (1999) suggested LR estimates are at least twice the SR estimates in their dynamic modelling of UK bus operators (i.e. –0.9).
- Balcombe et al. (2004) estimated an average (unweighted) value of –1.01 (3 studies), but with individual values varying between –0.85 and –1.32.
- Goodwin (1992) estimated an (unweighted) value of –0.65, although values ranged from –0.45 to –0.98.

The likely reason for the wide range in the LR results is (partly) related to the different definitions of the LR estimates and the uncertainty associated with obtaining LR estimates which tend to vary by place, time period and study.

A2.1.2 Disaggregate Estimates

A number of studies have disaggregated the market according to geographic, demographic and service factors. Some of the primary observations included:

- **Trip purpose and time of day**. Non-discretionary travel is generally found to be less elastic than discretionary travel; and hence, given the mix of trip purposes, peak travel is less elastic than off-peak travel. Balcombe et al. (2004) found an average SR bus fare elasticity of –0.26 for peak travel, –0.48 for off-peak travel. Habib et al., cited in Pratt et al. (2000), found that elasticities for work trips were typically less than half those for shopping trips (with values ranged from –0.05 to –0.09 for work trips to –0.15 to –0.25 for shopping trips). Often the peak elasticity is quoted at around half the off-peak estimate: a number of international studies have supported this conclusion, such as Balcombe et al. (2004), APTA (1991), Dasgupta et al. (1994), and Smith & McIntosh (1973).
- **Trip distance**. Fare elasticities for buses appear to be relatively high for very short journeys, dropping to a low value for medium distance, and then increasing gradually with distance, but finally falling again for long distances (Balcombe et al. 2004).

- **City size**. The US study by APTA (1991) found that the average elasticity for large cities (i.e. more than 1 million) was lower than the elasticity for smaller cities, indicating that public transport users in large cities are less sensitive to fare changes.
- **Conditional versus own mode**. Very few studies make specific reference to own mode and conditional elasticities. London Transport (1997) estimated a conditional elasticity of –0.35 and an average own mode elasticity of –0.64.

A2.2 Rail Fares

A2.2.1 Overall Estimates

Short Run (SR)

While the elasticity values appear to vary widely among systems, the average fare elasticity for rail services appears to be of a similar order of magnitude to bus, ranging from –0.10 to –0.60 (refer to Table A2 for details of the international evidence). However, the price sensitivity of rail travel demand is influenced by the type of rail service (i.e. metro compared to suburban rail):

- Typical values for metro services appear to be lower than bus; and
- Typical values for suburban services appear to be higher than bus.

Balcombe et al. (2004) provides one of the most comprehensive recent reviews of the rail literature, covering both the UK and international literature. It segmented rail demand into metro and suburban rail services, and concluded that SR values for metro services average –0.29, and for suburban rail –0.50. The Balcombe review noted that suburban rail has a higher elasticity than metro (and bus), possibly reflecting the likelihood of car as a competitor. It also compared these estimates to values in its earlier (TRRL) 1980 review, which estimated an elasticity of –0.18 for metro rail services and –0.50 for suburban rail, indicating that estimates for metro services appear to have increased over time.

Similarly, Pratt et al. (2000) reviewed the rail demand literature, particularly from studies in the US and Canada, and estimated an average (arc) elasticity of slightly lower than –0.20 for 'rapid transit' services. Pratt concluded that this value is consistently around half the bus fare elasticity in the same city. One possible explanation for this difference is that rapid transit typically operates where congestion and parking costs are highest, while itself offering higher speed advantages. The available alternatives are therefore less attractive, thus limiting shifts between public transport and private travel. Other possible factors behind the difference are trip lengths, journey purpose mix, and socio-economic mix of the users of the two modes.

The Pratt et al. value is not too dissimilar to fares elasticities derived by London Transport (1997) and Goodwin et al. (1992).

Medium Run (MR)

Very few studies, (either metro or suburban rail) have estimated the medium-run effect. Halcrow Fox et al. (1993b) estimated medium-run values of –0.45 for metro services and –0.80 for suburban rail services, each about 10% higher than their SR estimates.

Long Run (LR)

As for buses, it is commonly believed that rail fare elasticities increase over time. Asensio (2000) has suggested LR estimates around 1.5 times higher than SR estimates. Similarly, Goulcher (1991) derived LR estimates for London Underground of about 40% higher than SR values. The Balcombe et al. (2004) review estimated an LR value around twice than the SR estimate for metro services: the average LR value of –0.57 compared with the SR average of –0.29.

Owen & Phillips (cited in Goodwin et al. 1992) estimated a much higher LR elasticity for rail services of –1.08, with values ranging from –0.61 to –1.38. These estimates are more in line with LR bus elasticity estimates.

A2.2.2 Disaggregate Estimates

Few studies have estimated disaggregated rail fare elasticities. Some of the key findings are presented below and many of the relationships are similar to bus:

- **City size**. The study by Asensio (2000) in Spain suggested fare elasticity increases with city size, although this difference was marginal.
- **Trip purpose and time of day**. Peak demand is predominantly non-discretionary travel while off-peak trips are generally more discretionary and appear to be more sensitive to fare changes. However, although trip purpose is considered an important demand determinant, virtually no empirical evidence is available aside from an earlier study in Boston by Charles River Associates (1997) that estimated a work trip elasticity of –0.09 compared to –0.32 for shopping trips. Similarly, fare changes have been found to affect off-peak demand more than peak demand, although the rail evidence is limited. Studies by Mayworm et al. (1980) and Rendle et al. (cited in Pratt et al. 2000) generally found peak values around half the off-peak (peak values of –0.04 and –0.10, and off-peak values of –0.11 and -0.25 for New York and London respectively).
- **Urban and non-urban**. A difference appears to exist between urban rail and non-urban areas. Steer Davies & Gleave (1993b) found that rail fare elasticity estimates were substantially lower for commuting travel to London when compared to commuting travel outside London (i.e. –0.35 and –0.51 respectively). These differences probably reflect the more limited realistic travel options for trips to London.
- **Trip distance**. The general effect of distance on fare elasticity has also been given scant attention. Preston (1998, cited in Balcombe et al. 2004) found that rail fare elasticity generally decreases as distance increases, in both the short and long run. The Balcombe et al. (2004) review also concluded that, in general, rail fare elasticity decreases with distance, although there is conflicting evidence on the strength of this effect. (This effect explains, in part, why average rail fare elasticities are lower than bus fare elasticities.)

A2.3 Public Transport Fares

A2.3.1 Overall Estimates

Table A3 details the empirical literature on the patronage response to fare changes for public transport in general (typically for the full mix of public transport modes in the urban area). The most notable distinction between public transport and individual mode elasticities is by Pratt et al. (2000). They maintain that the fare elasticity value is influenced by the composition of the existing public transport modes. Pratt et al. estimate that the average fare elasticity for US cities, excluding those with rapid transit (i.e. metro), is about –0.40. They state that the inclusion of systems with rapid transit tends to lower the fare elasticity. For example, a sample drawn upon by Ecosometrics (cited in Pratt et al. 2000), which covered rapid rail and bus, found an average estimate of –0.28.

As noted by Oum et al. (1992), very few studies have separated the effects of short run and long run: most of the estimates reported were either SR values or did not explicitly state the time horizon. However, there is no reason to expect the SR versus LR relativities to differ from those outlined earlier for bus and for rail modes.

A2.3.2 Disaggregate Estimates

Very few studies have segmented the market according to time of day, trip purpose, trip length, etc. The major findings, which were generally consistent between bus and rail, included:

- **Trip purpose and time of day**. Non-discretionary travel was generally found to be less price sensitive than discretionary travel (Gunn 1998). Similarly peak travel was also found to be less elastic than off-peak travel (De Borger et al. 1996).
- **Trip distance and trip type**. A stated preference survey of Chicago transit travellers segmented the market by trip distance and found radial trips into the CBD to be less sensitive to fare change, probably reflecting both the need to travel to work and other options. Of particular interest was the higher elasticity of short journeys, which reflects the feasibility of walking as an alternative (Cummings et al. 1989).

A3. Australian & New Zealand Evidence

A3.1 Bus Fares

A3.1.1 Overall Estimates

Table A4 details the findings of our review of the Australian and New Zealand bus fare elasticity evidence. A comprehensive range of estimates is available from both literature reviews and primary research. Often the estimates for individual cities varied both within and between studies, and often it was not clear whether the study was referring to a long-run or short-run value. In most cases, unlagged time series have been interpreted as short-run estimates.

Short Run (SR)

Australia. Overall Australian bus fare elasticities were generally of the order of –0.3 to –0.4 (Travers Morgan 1982, BTE 1977, Dodgson 1985). However, studies undertaken in individual centres revealed elasticities which ranged from –0.48 in Adelaide, to as much as –0.8 in Hobart (Travers Morgan 1982, Shepherd 1972).

New Zealand. The evidence suggests that, overall, SR New Zealand estimates are similar to the weight of Australian (and international) evidence. Earlier studies by Wallis & Yates (1990) and Bly & Oldfield (1985) estimated an average SR value of around –0.3.

Several estimates found for individual New Zealand centres were significantly higher than these overall New Zealand values. A recent study by Booz Allen Hamilton (2001a) estimated an overall short-run estimate of –0.69 in Wellington. The author noted that the higher than average estimate is likely to reflect the relatively high proportion of short distance bus trips for which walking is a ready alternative.

Similarly, Travers Morgan (1989) and Wallis & Yates (1990) observed values between –0.4 and –0.6 in their studies of individual centres of Christchurch, Wellington and Dunedin.

Medium/Long Run (MR/LR)

Aside from a study by Galt & Eyre (1987), which estimated a value of –0.60 for Wanganui buses, no other evidence was found which examined either MR or LR effects.

A3.1.2 Disaggregate Estimates

Although a number of studies have examined the aggregate elasticity effects, relatively few have examined differences according to various market segments. Major findings included:

- **Time of day and trip purpose.** A number of studies have found that off-peak demand was more elastic than peak demand, with most studies estimating off-peak elasticity at 1.5 to 2 times the peak elasticity. Often the difference between the peak and off-peak is driven by the trip purpose, although very few studies made this distinction. (Taplin et al. (1999) estimated a commuter elasticity –0.15 for bus travel in Sydney.)
- **Passenger-type.** Related to the above, elasticities also tend to vary by passenger type, according to ability to pay as well as the discretionary nature of the trip. Typically elasticities are highest for pensioners, rather lower for other non-employed adults, and for children on non-school trips.
- **Trip distance.** Generally very short trips and very long trips were found to be the most price-sensitive. An earlier Melbourne study by Singleton (1978) found an especially high elasticity for trips within the city section (typically less than 1.0 km), because passengers can readily walk. In summary, a lower elasticity was observed for short/medium distance trips and a higher elasticity for very long trips, probably because other modes (i.e. train and car) can be used as a substitute.
- **Conditional and own mode elasticities.** As for the international evidence, very few studies stated whether the estimates are conditional or own mode, and even fewer quantify this difference, with the exception of the Brisbane study by Booz Allen Hamilton (2002b). The study used combined SP and RP data to estimate a (all day) conditional elasticity of –0.22 for Brisbane buses. This compares to a higher (all day) own-mode elasticity of –0.36.

A3.2 Rail Fares

A3.2.1 Overall Estimates

Table A5 summarises the Australian and New Zealand evidence relating to urban rail fare elasticities.

Short Run (SR)
Australia. Mixed results were found in terms of rail demand elasticities. Studies by BTE (1977) and Paterson (1972) found overall estimates around –0.3, similar to that for bus. However, a number of other studies found rail demand elasticity estimates to be somewhat lower than bus (i.e. of the order of –0.2). These estimates are more in line with international experience.

New Zealand. Few empirical studies have examined the demand response to rail fare changes in New Zealand, with the exception of a Wellington study by Travers Morgan (1985) which derived a SR run estimate of –0.32 and –0.43 for different functional forms.

Medium Run (MR) and Long Run (LR)
No evidence was found for either Australia or New Zealand on MR to LR rail elasticity estimates.

A3.2.2 Disaggregate Estimates

A number of studies in Australia and New Zealand have sought to disaggregate the data according to time of day, trip purpose, etc., particularly in terms of commuter rail demand. The major findings included:

- **Trip purpose and time of day**. Peak travel demand elasticities were around half those of the off-peak: values generally ranged from –0.10 to –0.30 in the peak and –0.30 to –0.50 in the off-peak. Particular attention has also been given to the peak commuter market in Sydney. Taplin et al. (1999) recently estimated a value of -0.19 for commuter trips in Sydney. This compares to earlier SR estimates by Hensher & Bullock (1979).
- **Conditional and own mode**. Booz Allen Hamilton (2002b) derived an own mode elasticity of –0.38 and a conditional elasticity of –0.27 for rail travel demand. As expected, the conditional elasticity values are generally smaller than own-price elasticities as fewer alternatives are available for passengers to switch to.

A3.3 Public Transport Fares

A3.3.1 Overall Estimates

Short Run (SR)
Table A6 summarises the Australian and New Zealand evidence on public transport fare elasticities in general.

Australia. Booz Allen Hamilton (2000) estimated overall SR estimates for Australia that ranged from –0.37 to –0.53 using different model formulations. Results were based on nine medium size centres and predominantly relate to bus mode. These results compare to earlier work by Bly & Oldfield (1985) who estimated a short-run value of –0.44 for Australia based on 'national' data. (A much lower estimate was obtained using more disaggregate towns data.) By comparison the BTE (1991) study derived a much lower SR elasticity of –0.25.

New Zealand. Similar to the Australian estimates, Bly & Oldfield (1985) estimated a SR value of –0.33.

Medium Run (MR) and Long Run (LR)

BTE (1991) provided the only evidence on MR and LR elasticity estimates. Values ranged from –0.55 in the MR to –0.80 in the LR.

A3.3.2 Disaggregate Estimates

Very few studies disaggregated the market according to market segment. The only empirical estimate obtained was by Shepherd (1972) who derived a peak work trip elasticity of –0.05.

A4. Other Factors for Consideration

A number of factors that can potentially influence the public transport fares elasticity are not often explored in the literature. The following three factors are considered in further detail below:

- The direction of the fare change;
- The level of fares (i.e. high fares versus low fares); and
- The magnitude of the fare change.

A4.1 Direction of the Fare Change

Very limited data exists to suggest that the patronage response to fare changes differs significantly according to the direction of the fare change. Most evidence available indicates that the fare elasticity for fare increases and decreases is very similar. For example, Mayworm et al. (cited in Pratt et al. 2000) in their review of 23 fare changes in the US, found that the fare elasticities were not significantly different for fare increases and fare decreases. Similarly Bly (1976), Fairhurst & Morris (1975) and Wardman (cited in Pratt et al. 2000) concluded that the elasticity for fares decreases was the same as the elasticity for fare increases.

Dargay & Hanly (1999) also found no indication of asymmetry of response in any of their models after specifically testing for evidence. However they noted that this may be because the fares analysed were primarily rising over time, with few instances of reductions: they suggested more disaggregate data including fare reductions would be needed to fully test the hypothesis.

Of the evidence available to date, only marginal differences between fare increases and fare decreases have been found. Some of the key findings included:

- Hensher and Bullock (1979) found that the fare elasticity for Sydney rail fare increases was almost the same as that for fare decreases (i.e. values of –0.21 and –0.19 respectively).

- Dargay & Hanly (1999) examined disaggregate county-level data, and found an indication that the response to fare increases was slightly higher for fare increases compared to fare decreases (i.e. values ranged from –0.27 to –0.56 for fare decreases compared to –0.36 to –0.74 for fare increases).

A4.2 Base Level of the Fare

The difference in fare elasticities between situations with high base fares and those with low fares has also been given scant attention in the literature. TRRL (1980) explains the likely response using the generalised cost framework. It maintains that passengers can be expected to be more price-sensitive to a given percentage fare change because fares form a larger portion of the total travel cost (in time, money and effort). Thus fares elasticities would be expected to increase at higher levels. However, it found no empirical evidence to support this.

The principal source of evidence on variations in fare elasticities with fare levels is Dargay & Hanly (1999). The summary of this report states that:

> *There is statistical evidence that demand is more price-sensitive at higher fare levels. This conclusion is drawn on the basis of a model in which the fare elasticity is related to the fare level. The variation in the elasticity ranges from –0.13 in the short run and –0.27 in the long run for the lowest fares (27 pence in 1995 prices) to –0.77 in the short run and –1.6 in the long run for the highest fares (1 pound in 1995 prices).*

The analysis by Dargay & Hanly and their conclusions are the most persuasive of all the available references. They are based on econometric analyses of UK bus passenger data for the period 1976-96, at national, regional and county levels, and testing a range of model formulations. Their conclusions are broadly consistent with the hypothesis that fares elasticities are directly proportional to the fare level. This implies that the patronage proportionate response is similar for all absolute ($) fare changes, irrespective of fare levels.

A4.3 Magnitude of the Fare Change

Relatively little empirical evidence is available on how fare elasticities change with the magnitude of the fare change – although it is often asserted that the response to large changes is proportionately greater than the response to small changes. However, most of the limited evidence does not support this assertion. For instance Mayworm et al. (1980, and cited in Pratt et al. 2000) concluded that the magnitude of the change has been shown to have no discernible effect on fare elasticity.

However BGC (cited in Rosenberg et al. 1997) concluded that large changes in public transport fares have a more than proportional effect compared to small fare changes. Rosenberg et al. (1997) examined the effect on public transport use at different fare levels. Their results found that elasticities were lower at high price levels than at the current price level. They explain that normally the price elasticity increases when price rises, and that this outcome potentially reflects that the rise in fares has forced public transport users into their cars, while only so-called public transport captives continue to use public transport.

A5. Conclusions

A5.1 Aggregate Estimates

Short Run (SR)

This review of international empirical evidence indicates a large measure of consistency between fare elasticity estimates in different countries, after allowing for market characteristics.

As noted in Section A2.1.1, the earlier influential international reviews concluded that a reasonable 'rule of thumb' for short-run urban public transport fare elasticity was about –0.30, which was more-or-less consistent with the Simpson-Curtin formula of –0.33. Until the 1990s these figures were generally accepted as relevant to most developed countries. The more recent international evidence indicates that rather higher values, around –0.40, may now be appropriate. No comprehensive appraisal appears to have been undertaken internationally as to the factors behind this apparent increase in values, although various factors could be hypothesised (e.g. reduction in the proportion of truly 'captive' travellers; changes in the journey purpose mix of public transport users).

While the consistency in elasticity estimates in different countries is good, some systematic differences between countries are evident. Balcombe et al. (2004)) concluded that UK elasticity values were higher than for other developed countries on average: it suggested this might be related to the higher fare levels in UK, the different mix of trip purposes, and/or the perceived poorer quality of public transport services.

The evidence on fares elasticities for New Zealand does not suggest they differ significantly from those for Australia or from the weight of international evidence. If anything, the New Zealand estimates may be towards the top end of the international range, broadly on a par with the UK figures. Typical SR fares elasticity ranges and recommended 'central' values for New Zealand are:

• **Bus:**	recommended average	–0.40
	typical range	–0.20 to –0.60
• **Rail:**	recommended average	–0.30
	typical range	–0.20 to –0.50

The evidence is unclear whether the difference in estimates between bus and rail modes reflects intrinsic qualities of the two modes; or that it reflects more the different market characteristics of the trips on each mode (e.g. trip lengths, CBD versus non-CBD trips).

Medium Run (MR) and Long Run (LR)

The weight of international evidence is that LR fare elasticities are typically double SR values (range is generally 1.5 times to 3.0 times).

While data on these relativities is very limited for New Zealand (or Australia), there is no reason to think that the international conclusion would not be applicable to New

Zealand. Hence our recommended 'central' LR values would be twice the SR values given above.

A5.2 Disaggregate Estimates

The estimates given above relate to the aggregate market for public transport (or for bus and rail modes separately). Internationally, substantial evidence on elasticity differences exists for disaggregated market segments. A much lesser amount of such disaggregated evidence is available for New Zealand (or Australia); but such evidence as is available is consistent with the wider international evidence.

Based on the evidence overall, the following main conclusions are drawn on disaggregated fares elasticity values for the New Zealand market:

- **Trip purpose and time period.** Elasticities for off-peak/non-work trips are typically twice those for peak/work trips; while weekend elasticities are higher still.
- **Trip distance.** Elasticities are highest for very short trips (up to 1-2 km, where walking is a ready substitute); lowest at medium distances (typically 4-8 km); then increase somewhat, but decrease for longest distance trips (often beyond the urban area).
- **City size.** Some international evidence that elasticities are lower in larger cities (over 1 million population), although this is not conclusive and likely to be compounded with other effects, such as trip length.

A5.3 Other Factors

Based on international evidence, our conclusions on the variation in elasticity estimates with three other factors are as follows:

- **Base fare level.** Some strong evidence (from the UK) that fares elasticities are more-or-less proportional to the absolute level of fares (rather than constant over different fare levels).
- **Magnitude of fare change.** Elasticity estimates do not vary significantly with the magnitude of the fare change.
- **Direction of fare change.** Elasticity estimates do not vary significantly with the direction (increase or decrease) of the fare change.

Table A1: Bus Fare Elasticities – International Evidence

City/Country	Study Type and Period	Elasticity				Market Segment	Comments	Source	Rank
		Short Run	Medium Run	Long Run	Not Stated				
UK	Literature review	-0.43	-0.56	-1.01			SR: -0.07 to -0.86, SD 0.18, 33 cases MR: -0.51 to -0.61, SD 0.07, 2 cases LR: -0.85 to -1.32, SD 0.26, 3 cases	Balcombe et al. (2004)	←← ←
International (Outside the UK)	Literature review	-0.37					-0.23 to -0.58, SD 0.11, 11 cases	Balcombe et al. (2004)	←←
Various (UK, international)	Literature review (RP, conditional)	-0.36	-0.51				SR: -0.23 to -0.52, SD 0.10, 9 cases MR: 1 case	Balcombe et al. (2004)	←←
Various					-0.30		SD: +/- 0.10 This average estimate is based on studies in New York, Paris and London.	Lago et al. (1981c)	←
Europe	Transportation Modelling	-0.34				Small Cities (<500,000)	Model contained 89 observations and obtained statistically significant results (i.e. SE 0.06 and 0.08 for small and large cities respectively).	ISOTOPE (1996)	←← ←
		-0.50				Large Cities (>500,000)			
		-0.42				Overall			
UK	Literature review	-0.26				Peak	0.0 to -0.47, SD 0.14, 9 cases	Balcombe et al. (2004)	←←
		-0.48				Off-Peak	-0.14 to -1.00, SD 0.26, 10 cases		
International (Outside the UK)	Literature review	-0.24				Peak	-0.14 to -0.32, SD 0.07, 8 cases	Balcombe et al. (2004)	←←
		-0.51				Off-Peak	-0.29 to -0.73, SD 0.20, 8 cases		
USA	Before and After	-0.4				Average	Based on before and after survey data collected from 52 US Transit systems. The model was generally well specified and yielded statistically significant results. Used a lagged variable using an ARIMA transformation. Noted that the elasticity levels of the individual transit systems varied from -0.12 to -0.85. The local population, work places, income, driving conditions, transit services etc. cause different levels of sensitivity of travellers to fare changes. In any event, the variation clearly identifies the danger in applying the Simpson-Curtin rule to all areas.	APTA (1991)	←← ←
		-0.23				Peak			
		-0.42				Off-Peak			
		-0.43				Small Cities			
		-0.36				Large Cities			
		-0.27				Peak Small Cities			
		-0.48				Off-Peak Small Cities			
		-0.18				Peak Large Cities			
		-0.39				Off-Peak Large Cities			

Table A1: Bus Fare Elasticities – International Evidence

City/Country	Study Type and Period	Elasticity				Market Segment	Comments	Source	Rank
		Short Run	Medium Run	Long Run	Not Stated				
Various	Time Series (1965-82)		-0.26 -0.31			National Data Towns Data	SD: +/- 0.04 SD: +/- 0.02 based on analysis of data from 16 countries over the period 1965 to 1982 and data from 117 individual cities over the period 1970 to 1982. Time-lagged regression indicates values can be interpreted as medium-run estimates.	Bly & Oldfield (1985)	←←
Leeds	Transport Modelling				-0.20 -0.40	Peak Off-Peak	Modelling of five UK Cities. Noted that the bus mode shares for peak travel ranged from 8% in Bristol to 22% in Leeds.	Dasgupta et al. (1994)	←←
Bristol					-0.31 -0.62	Peak Off-Peak			
Sheffield					-0.08 -0.16	Peak Off-Peak			
Derby					-0.33 -0.49	Peak Off-Peak			
Reading					-0.18 -0.41	Peak Off-Peak			
UK	Before and after (1971/72)	-0.27 -0.87				Peak Off-Peak	Bus demonstration project	Smith & McIntosh (1973)	
UK	Time Series (1977-83)	-0.33				Adult	Statistically significant result (i.e. 0.05 SE)	McKenzie (1984)	
Houston and San Diego (USA)	Cross-sectional				-0.32			Kain & Lui (1999)	
San Francisco (USA)	Mode choice modelling				-0.86	Work Trips		McFadden (1974), cited in Gomez-Ibanez et al. (1999)	
San Diego	Before and after (1972/73)	-0.40 to -0.45					Author noted that the reduced fares generated additional 23% patronage.	Kemp (1974)	←
Cincinnati	Before and after (1973)	-0.40					Author noted that the reduced fares generated additional 32% patronage.	Kemp (1974)	←
Atlanta	Before and after (1972)	-0.15 to -0.20					Author noted that the reduced fares generated additional 19% patronage and that demand levels stabilised 3-6 months after the fare change.	Kemp (1974)	←

Table A1: Bus Fare Elasticities – International Evidence

City/Country	Study Type and Period	Elasticity				Market Segment	Comments	Source	Rank
		Short Run	Medium Run	Long Run	Not Stated				
Portland (USA)	Time Series (1971-82)				-0.29 -0.13 to -0.42 -0.35 to -0.90	System Geographic area Individual routes	Several models were developed including one for the system on the whole, six representing distinct geographic sectors and nine for individual bus routes.	Kyte et al. (1985), cited in APTA (1991)	←
Norway	Cross-sectional (1991/92)				-0.63			EXTRA Project, cited in Nijkamp & Pepping (1998)	←
USA	Literature review	-0.40					Average arc elasticity estimate calculated from a range of studies. Author noted that off-peak elasticities are approximately twice the peak.	Pratt et al. (2000)	←← ←
USA		-0.05 to -0.09 -0.15 to -0.25				Work Trips Shopping Trips	Based on results obtained from studies in Baltimore, Birmingham and Richmond.	Habib et al., cited in Pratt et al. (2000)	←←
London	Time Series (1971-82)				-0.35		95% CI: -0.29 to -0.41	Fairhurst & Edwards (1996)	←
UK (excluding London)	Time Series (1971-86)				-0.38		95% CI: -0.07 to -0.68	Fairhurst & Edwards (1996)	←
Various	Literature Review (segmented by method)	-0.21 -0.28 -0.37	-0.55	-0.65	-0.40	6 months 0 to 6 months 0 to 12 months 4 or more years 10 years or more Overall average (50 studies)	SD 0.12, 3 cases (before and after) SD 0.13, 8 cases (explicit short run) SD 0.18, 24 cases (unlagged Time Series) SD 0.20, 8 cases (explicit long run) SD 0.18, 4 cases (equilibrium models) Overall average (50 studies)	Goodwin (1992)	←← ←
UK – London	Literature Review	-0.30 to -0.45	-0.30 to -0.80	-0.40 to -1.20			Estimates derived from literature review, as part of studies for London congestion charging scheme.	Halcrow Fox et al. (1993b), cited in Balcombe et al. (2004)	←

Table A1: Bus Fare Elasticities – International Evidence

City/Country	Study Type and Period	Elasticity				Market Segment	Comments	Source	Rank
		Short Run	Medium Run	Long Run	Not Stated				
UK - England	Econometric modelling, with lagged model (1988-97)	-0.33 to -0.44		-0.62 to -0.86			Range of models using pooled county data, with different fare specifications. SR less than 1 year, LR 7+ years. Best estimates c. -0.40 SR, -0.75 SR. LR values typically twice SR values. Strong evidence that fare elasticity is approx proportional to fare level. Elasticities for shire counties typically 1.5 to 2.0 times metropolitan areas. Full-fare elasticities in order of half concession elasticities.	Dargay & Hanly (2001)	←← ←
Various	Literature review				-0.3 -0.6	Commuting and Business Leisure	Reviewed the literature for possible differences in price sensitivity for different trip purposes.	Fowkes et al. (1993), cited in Dargay & Hanly (1999)	←←
Spain	Time Series and cross-sectional (1980-88)	-0.06 to -0.39 -0.28		-0.06 to -0.39 -0.30	Range Average		Data is from 11 Spanish bus operators. Most model specifications yielded statistically significant t-stats.	De Rus (1990)	←← ←
London (UK)	Time Series (1970-95)	-0.64 -0.35				Own mode Conditional	This research updates earlier research reported in LT Report R273. Noted that the comparable conditional fare elasticity was -0.40.	London Transport (1997)	←← ←
UK	Cross-sectional			-0.87				Goodwin (1987)	←
UK-England	Econometric modelling (1977-96)	-0.22 to -0.33		-0.44 to -0.62			Range of models including partial adjustment (lagged) model and variable elasticity model. Used national data (1977-96), regional data (1985-96) and metro area data (1987-96). Conclusions state that most likely values for GB as a whole are -0.35 SR/-0.85 LR, although not clear that these are consistent with the individual model results.	Dargay & Hanly (1999)	←← ←

Table A2: Rail Fare Elasticities – International Evidence

City/Country	Study Type and Period	Elasticity				Market Segment	Comments	Source	Rank
		Short Run	Medium Run	Long Run	Not Stated				
Various					-0.15		SD: +/- 0.13 This average estimate is based on studies in New York, Paris and London.	Lago et al. (1981c)	←
Spain	Panel data (1991-95)	-0.30 -0.32				Small Cities (<500,000) Large Cities (>500,000)	Quarterly data from 11 urban centres. Author concluded long run elasticities are 1.56 times the short run. Results were statistically significant (i.e. t-stats were -3.23 and -4.68 for small and large centres respectively).	Asensio (2000)	←← ←
London (UK) (Underground)	Time Series (1971-95)	-0.49 -0.20				Own mode elasticity Conditional elasticity	This research updates earlier research reported in LT R273. Noted that the comparable conditional fare elasticity in R273 was -0.19.	London Transport (1997)	←← ←
San Francisco (USA)	Mode choice modelling	-0.86				Work Trips		McFadden (1974), cited in Gomez-Ibanez et al. (1999)	←
Various	Literature review				-0.79		SD: 0.32, 92 Cases This value includes London and provincial commuter services.	Goodwin (1992)	←← ←
UK		-0.69		-1.08		SR range: -0.4 to -0.76 LR range: -0.61 to -1.38	Explicit SR and LR formulation.	Owen & Phillips (1987), cited in Goodwin (1992)	←←
London (UK) (Underground)	Pooled Time Series and cross-sectional data (1981-89)				-0.43	1984		Goulcher (1991)	←
					-0.53	1985			
					-0.47	1986			
					-0.42	1987			
					-0.61	1988			
					-0.46	1989			
				-0.60		Overall			
London (UK) (Underground)	Time Series (1970-85)	-0.20		-0.40			Conditional elasticity (i.e. assumed no change in the differential between LU and Bus fares).	Goodwin et al. (1992)	←←
Netherlands	Cross-sectional (1986)				-0.77			Gunn (1977), cited in Nijkamp & Pepping (1998)	←

Table A2: Rail Fare Elasticities – International Evidence

City/Country	Study Type and Period	Elasticity				Market Segment	Comments	Source	Rank
		Short Run	Medium Run	Long Run	Not Stated				
Various	Literature review	-0.17 to -0.18					Arc estimate	Pratt et al.(2000)	←← ←
New York (USA)		-0.22 -0.20				Commuter - Long Island Commuter - Metro		Charles River Associates (1997), cited in Pratt et al. (2000)	←
Boston (USA)	Cross sectional (1963/64)				-0.09 -0.32	Work trips Shopping trips		Charles River Associates, cited in Kemp (1973, 1974)	←
UK - Metro	Literature review	-0.29		-0.57			SR: -0.15 to -0.55, SD 0.13, 16 cases LR: -0.40 to -0.69, SD 0.15, 3 cases	Balcombe et al. (2004)	←←
International (outside the UK) - Metro	Literature review (RP, conditional)	-0.21					-0.12 to -0.31, SD 0.08, 8 cases	Balcombe et al. (2004)	←←
UK - Metro	Literature review (RP, conditional)	-0.26		-0.57			SR: -0.15 to -0.43, SD 0.11, 10 cases LR: -0.40 to -0.69, SD 0.15, 3 cases	Balcombe et al. (2004)	←←
Various - Surface Rail	Literature review (all methods)	-0.58 -0.37 -0.50				UK International Overall	-0.10 to -1.02, SD 0.28, 21 cases -0.09 to -0.78, SD 0.18, 11 cases -0.10 to -1.02, SD 0.26, 32 cases	Balcombe et al. (2004)	←←
Various – Surface Rail	Literature review (RP, conditional)	-0.51 -0.31				UK International	-0.08 to -1.02, SD 0.31, 11 cases -0.09 to -0.48, SD 0.12, 9 cases	Balcombe et al. (2004)	←←
London (UK)					-0.10 -0.25	Peak Off-peak		Rendle et al. (1978), cited in Pratt et al. (2000)	←
UK		-0.76 -0.48		-0.83 -0.55		Very short trips (Band 1) Very long trips (Band 8)	Examined the price sensitivity of adult single fares by distance band.	Preston (1998), cited in Balcombe et al. (2004)	←
SE England	Stated preference				-0.35 -0.51	Commuting to London Destination up to 15 miles Commuting Non-London Destination up to 15 miles		Steer Davies Gleave (1993b), cited in Balcombe et al. (2004)	←

Table A3: Public Transport Fare Elasticities – International Evidence

City/Country	Study Type and Period	Elasticity				Market Segment	Comments	Source	Rank
		Short Run	Medium Run	Long Run	Not Stated				
Netherlands		-0.29 to -0.32	-0.35 to -0.39					Meurs et al., cited in Balcombe et al. (2004))	←← ←
Chicago	Stated Preference	-0.26				Peak central area		Cummings et al. (1989)	←
		-0.39				Off-peak central area			
		-0.11 to -0.13				Peak radial			
		-0.36 to -0.39				Off-peak radial			
		-0.19 to -0.24				Peak local			
		-0.41 to -0.44				Off-Peak local			
		-0.29				Peak <2miles			
		-0.49				Off-peak <2miles			
		-0.19				Peak overall			
		-0.44				Off-peak overall			
		-0.33				Average all day			
Paris					-0.23	Work - white collar		Gunn et al. (1998)	←
					-0.24	Work - blue collar			
					-0.26	Business			
					-0.84	Education			
					-0.29	University			
					-0.80	Regular shopping			
					-0.30	Other shopping			
					-0.45	Other			
					-0.55	Non-home based work			
					-0.42	Non-home based other			
					-0.34	All Trips			
Belgium	Transportation Model				-0.35	Peak		De Borger et al. (1996)	←←
					-0.80	Off-Peak			
US/Europe	Literature Review				-0.1 to -0.6		Commonly observed range	TRRL (1980)	←
Various	Literature Review of Transit Fare Demonstration	-0.28					SD +/- 0.16, 67 cases	Lago et al. (1981c)	←
Various	Literature Review of studies using Time Series data	-0.42					SD: +/- 0.24, 28 cases	Lago et al. (1981c)	←

Table A3: Public Transport Fare Elasticities – International Evidence

City/Country	Study Type and Period	Elasticity				Market Segment	Comments	Source	Rank
		Short Run	Medium Run	Long Run	Not Stated				
Various	Literature Review of Studies using cross-sectional data	-0.53					SD: +/- 0.35, 28 cases	Lago et al. (1981c)	←
Netherlands	Time Series (1981 to 1986)	-0.35 to -0.40					Constant elasticity estimate.	Cheung & Tinselboer (1988)	←←
Helsinki (Finland)	Cross-section (1988)				-0.48		Logit formulation.	EXTRA Project, cited in Nijkamp & Pepping (1998)	←
Helsinki (Finland)	Cross-section (1995)				-0.56		Nested Logit formulation.	EXTRA Project, cited in Nijkamp & Pepping (1998)	←
Finland	Repeated Cross-section (1966 to 1990)				-0.75		Demand is measured in terms of person kms for both urban and interurban coverage.	Sullustrom (1995), cited in Nijkamp & Pepping (1998)	←
Netherlands	Panel (1984/85)				-0.35 to -0.40		Urban and semi-urban areas.	EXTRA Project, cited in Nijkamp & Pepping (1998)	←
Netherlands	Time Series (1980 to 1986)				-0.35 to -0.50			BCG (1988), cited in Nijkamp & Pepping (1998)	←
Netherlands	Time Series (1950 to 1980)				-0.51		Demand is measured in terms of person kms and covers both urban and semi-urban areas.	Roodenburg (1983), cited in Nijkamp & Pepping (1998)	←
Netherlands	Time Series (1965 to 1981)				-0.53 to -0.80		Demand is measured in terms of person kms.	Fase (1986), cited in Nijkamp & Pepping (1998)	←
Netherlands	Time Series (1977 to 1991)				-0.74		Demand is measured in terms of person kms and covers both urban and semi-urban areas.	Oum (1992), cited in Nijkamp & Pepping (1998)	←
Oslo (Norway)	Cross-section (1990/91)				-0.40			EXTRA Project, cited in Nijkamp & Pepping (1998)	←
UK	Cross-section (1991)				-0.15		Urban and inter-urban areas.	EXTRA Project, cited in Nijkamp & Pepping (1998)	←

Table A3: Public Transport Fare Elasticities – International Evidence

City/Country	Study Type and Period	Elasticity				Market Segment	Comments	Source	Rank
		Short Run	Medium Run	Long Run	Not Stated				
Australia	Literature Review	-0.37					SD 0.06, 14 cases	TRRL (1980), cited in Halcrow Fox (1995)	←
UK		-0.33					SD 0.03, 39 cases		
USA		-0.23					SD 0.03, 31 cases		
West Germany		-0.34					SD 0.04, 13 cases		
France, Netherlands, Italy and New Zealand		-0.31					SD 0.07, 6 cases		
Various		-0.30					SD 0.02, 103 cases		
Various	Literature Review				-0.01 to -0.78	Overall Range	Author notes that these results are consistent with other studies.	Oum et al. (1992)	←←
					-0.10 to -0.60	Most common range			←
Germany	Time Series	-0.22					Overall average for 14 German cities.	Frank (1990), cited in Halcrow Fox (1995)	←

Table A4: Bus Fare Elasticities – Australian and New Zealand Evidence

City/Country	Study Type and Period	Elasticity				Market Segment	Comments	Source	Rank
		Short Run	Medium Run	Long Run	Not Stated				
Sydney (Australia)	RP and SP joint model (1996/97)				-0.15	Commuter Trips	Weighted sums of various market segments.	Taplin et al. (1997, 1999)	←←←
Melbourne (Australia)	Time Series (1972-76)	-0.11				Government Buses	Trips in Melbourne CBD. Results were significant.	Singleton (1978) Brown & Singleton (1981)	←
		-0.35				Private Buses			
		-0.37				Tram			
						Government bus by trip length:			
		-1.39				City section (adult)			
		-0.28				One section (adult)			
		-0.85				Ten or more sections (adult)			
Wellington (New Zealand)	Time Series (1998-00)	-0.69				Overall	95% CI: -0.46 to -0.91	Booz Allen Hamilton (2001a)	←←←
		-0.50				Peak	95% CI: -0.18 to -0.82		
		-0.83				Off-Peak	95% CI -0.58 to -1.07 Noted the difference between peak and off-peak estimates was not statically significant. Short/medium run estimates – date related to c.2 years before, 1 year after fare increase on Wellington City services. Author suggests the higher than average estimate for Wellington may reflect the relatively high proportion of short distance bus trips for which walking is a ready alternative.		
Brisbane (Australia)	RP and SP joint model (2001/02)					Conditional elasticity:	All results were statistically significant. Conditional: reflects the % change in trips given a 10% rise in all fares. Own mode: reflects the % change in trips given a 10% increase in own mode fare.	Booz Allen Hamilton (2002b)	←
					-0.13	Peak			
					-0.29	Off-Peak			
					-0.22	All Day			
						Own mode elasticity:			
					-0.25	Peak			
					-0.45	Off-Peak			
					-0.36	All Day			
Adelaide	Time Series (1961-79)	-0.37				All	-0.20 to -0.54	Travers Morgan (1980a)	
		-0.2 to -0.3				Peak	Peak/off-peak estimates are suggested values only.		
		-0.3 to -0.4				Off-Peak			

Table A4: Bus Fare Elasticities – Australian and New Zealand Evidence

City/Country	Study Type and Period	Elasticity				Market Segment	Comments	Source	Rank
		Short Run	Medium Run	Long Run	Not Stated				
Adelaide	Before and after (1980/81)	-0.31 -0.27				Arc elasticity - adult passengers only Point elasticity -adult passengers only	95% CI: -0.04 to -0.60 95% CI: -0.03 to -0.51	Travers Morgan (1982)	
Australia	Derived value based on Reviews				-0.30 -0.15 -0.45	Overall Peak Off-Peak	Overall value is based on empirical literature and estimates provided by 6 capital cities.	Dodgson (1985)	←
Adelaide	Time Series (1959/60-1973/74)	-0.48						BTE (1978), cited in Travers Morgan (1979)	
Adelaide	Anecdotal Estimate				-0.15 -0.45	Peak Off-Peak	Should be treated as giving relative indications only.	Amos & Starrs, cited in Dodgson (1985)	
Australia	Pooled Time Series (1955/56 to 1973/74)	-0.35				Overall	Overall estimate. Based on pooled data from 6 Australian capital cities. Aggregate data give -0.29 (range -0.49 to +0.03 for individual cities).	BTE (1977)	←←
Auckland (New Zealand)	Time Series (1967-78)	-0.24					Time Series data – treated as medium-run estimates.	Pringle (1979)	←
Wanganui (New Zealand)	Time Series (1978-85)			-0.60			Fare variable lagged by one quarter. Authors note that the use of lagged data indicates that the elasticity is likely to reflect medium- to long-run effects.	Galt & Eyre (1987)	
Christchurch	Time Series (1975-89)	-0.51, -0.46 -0.41, -0.44				Time Series model Annual change model	SE: +/- 0.13 SE: +/- 0.40 Two values relate to analysis with/without unemployment variable.	Travers Morgan (1989)	←←
New Zealand	Time Series (1974/75 - 1988/89)	-0.34 -0.32				Log model form First Difference model form	SE 0.16 (significant) SE 0.23 (not significant) Model is based on data from 7 urban centres. The authors noted that few fares elasticities for individual centres were statistically significant.	Wallis & Yates (1990) Travers Morgan (1990a)	←←←

Table A4: Bus Fare Elasticities – Australian and New Zealand Evidence

City/Country	Study Type and Period	Elasticity				Market Segment	Comments	Source	Rank
		Short Run	Medium Run	Long Run	Not Stated				
Wellington (New Zealand)	Time Series (1974/75 - 1988/89)	-0.63 -0.47				Log model form First Difference model form	Results statistically significant.	Wallis & Yates (1990) Travers Morgan (1990a)	←
Christchurch (New Zealand)	Time Series (1974/75 - 1988/89)	-0.45 -0.43				Log model form First difference model form	Results statistically significant.	Wallis & Yates (1990) Travers Morgan (1990a)	←
Dunedin (New Zealand)	Time Series (1974/75 - 1988/89)	-0.43 -0.47				Log model form First difference model form	Results statistically significant.	Wallis & Yates (1990) Travers Morgan (1990a)	←
Auckland (New Zealand)	Before and after (1970)	-0.30				Interpeak	Fare experiment in 1970 by the Auckland Transport Committee (flat fare interpeak periods). The experiment was terminated after 10 weeks.	Auckland Metropolitan Transport Committee (1971). cited in Oldfield (1974)	←
Hobart (Australia)	Time Series (1955-71)	-0.9						Shepherd (1972), cited in Travers Morgan (1979)	
Auckland (New Zealand)	Anecdotal evidence from operators				-0.10 to -0.15 -0.25 to -0.50	Peak Off-Peak	Author suggests the anecdotal evidence for Auckland is supported by the empirical literature.	Travers Morgan (1988)	
Christchurch (New Zealand)	Anecdotal evidence from operators	-0.30					Author noted that this value recently fell to -0.20.	Travers Morgan (1988)	
Dunedin (New Zealand)	Anecdotal evidence from operators				-0.30		This value was based on a 10% fare change. The author notes that a higher absolute value was estimated for a 20% fares increase.	Travers Morgan (1988)	
New Zealand	Cross section (1981)			-0.13			26 urban centres. Result was not significant.	Galt & Eyre (1987)	←

Table A5: Rail Fare Elasticities – Australian and New Zealand Evidence

City/Country	Study Type and Period	Elasticity				Market Segment	Comments	Source	Rank
		Short Run	Medium Run	Long Run	Not Stated				
Sydney (Australia)	RP and SP joint model (1996/97)				-0.19	Commuter trips	Weighted sums of various market segments.	Taplin et al. (1997, 1999)	←←←
Australia	Pooled Time Series (1959/60 to 1973/74)	-0.37				Overall	Based on pooled data from 6 capital cities. Aggregate data gives -0.35 (range -0.83 to +0.25 for individual cities).	BTE (1977)	←←
Australia					-0.10 -0.30	Peak Off-Peak		BTE (1977), cited in Travers Morgan (1979)	
Sydney (Australia)	Before and after (1971)	-0.30 -0.60				6 months after the increase 8 months after the increase	Modelled the effect of the 50% increase in rail fares in Sydney, specifically rail travel by commuters living in a northern Sydney suburb. Shrinkage ratios of 0.24 and 0.44 were calculated the effects of the fare change over a range of time horizons.	Paterson (1972)	
Perth (Australia)	Before and after			-0.71 -0.69		Work trips by distance Short (< 15km) Long (> 15km)	Estimates are arc elasticities. Examined the effect of the introduction of the Perth flat fare system on patronage. The flat fare system had the effect of lowering fares for longer journeys and increasing fares for longer journeys.	Shea (1976), cited in Travers Morgan (1979)	
Sydney (Australia)	Cross-sectional				-0.018	CBD work trips	Point elasticity estimate	Smith (1975), cited in Travers Morgan (1979)	
Sydney (Australia)					-0.10 -0.30	Peak Off-Peak		BTE (1978), cited in Luk & Hepburn (1993)	←
Sydney and Melbourne	Derived value based on reviews				-0.15 -0.45 -0.30	Peak Off-Peak Overall	These estimates were based on the empirical literature and verbal advice from authorities.	Dodgson (1985)	←
Adelaide	Anecdotal estimate?				-0.20 -0.57	Peak Off-Peak	Should be treated as giving relative indications only.	Amos & Starrs, cited in Dodgson (1985)	←
North Sydney (Australia)	Before and after (1976)	-0.20 -0.17				Commuters/peak	Estimates the effect of a 20% rail fare reduction (May 1976) on modal choice behaviour of commuters working in North Sydney. Arc elasticity estimate. Result was statistically significant.	Hensher & Bullock (1979)	←←
Sydney (Australia)	Cross-sectional				-0.57	Work trips		Hensher (1972), cited in Travers Morgan (1979)	

Table A5: Rail Fare Elasticities – Australian and New Zealand Evidence

City/Country	Study Type and Period	Elasticity				Market Segment	Comments	Source	Rank
		Short Run	Medium Run	Long Run	Not Stated				
Adelaide	Time Series (1961-79)	-0.40 -0.2 to -0.3 -0.4 to –0.5				Overall Peak Off-Peak	95% CI: +/ -0.26 Peak/off-peak are suggested values only.	Travers Morgan (1980a)	←
Melbourne (Australia)	Time Series (1971/72 – 1995/96)	-0.37 to -0.64					Results were statistically significant.	Booz Allen Hamilton (1999)	←←
Brisbane (Australia)	RP and SP joint model (2001/02)				 -0.20 -0.35 -0.27 -0.28 -0.53 -0.38	Conditional elasticity: Peak Off-Peak All Day Own mode elasticity: Peak Off-Peak All Day	All results were statistically significant. Conditional: reflect % change in trips given a 10% rise in all fares. Own mode: reflects % change in trips to a 10% increase in own mode fare.	Booz Allen Hamilton (2002b)	←←
Sydney (Australia)	Time Series (10 years to 1984)	-0.21				Sydney suburban rail patronage	95% CI: -0.07 to -0.34. Notes that the impact of the fare change deferred 4 months after change occurs.	Gallagher (1985)	←
Wellington	Anecdotal evidence from operators	-0.15					Rule of thumb used for NZ Rail services. Author suggests that the low estimates in Wellington may reflect the effects of a congested central area with high service levels and higher densities.	Travers Morgan (1988, 1990c)	

Table A5: Rail Fare Elasticities – Australian and New Zealand Evidence

City/Country	Study Type and Period	Elasticity				Market Segment	Comments	Source	Rank
		Short Run	Medium Run	Long Run	Not Stated				
Sydney (Australia)	Stated preference (1992)		-0.29			Short CBD Peak	No evidence of the statistical significance of the estimates. All figures represent short/medium run mode share estimates (no allowance for generation, etc.).	Steer Davies Gleave (1993c)	
			-0.62			Short CBD Off-Peak			
			-0.78			Short Non CBD Peak			
			-0.66			Short Non CBD Off-Peak			
			-0.19			Med CBD Peak			
			-0.25			Med CBD Off-Peak			
			-0.28			Med Non CBD Peak			
			-0.36			Med Non CBD Off-Peak			
			-0.08			Long CBD Peak			
			-0.12			Long CBD Off-Peak			
			-0.18			Long Non CBD Peak			
			-0.21			Long Non CBD Off-Peak			
Wellington (New Zealand)	Time Series (1968/69 to 1983/84)		-0.43			Log Formulation	SE: 0.11	Travers Morgan (1985, 1990c)	←←←
			-0.32			First Difference Formulation	SE: 0.14		

Table A6: Public Transport Fare Elasticities – Australian and New Zealand Evidence

City/Country	Study Type and Period	Elasticity				Market Segment	Comments	Source	Rank
		Short Run	Medium Run	Long Run	Not Stated				
Australia	Time Series (1979-89)	-0.25	-0.55	-0.80			Note that the total is an implied elasticity from the two periods (i.e. 1 to 4 quarters back and 5 to 8 quarter back).	BTE (1991)	←←←
Australia (9 cities)	Pooled Time Series (1984/85 to 1998/99)	-0.53 -0.48 -0.37				Aggregate model Model with time trend Model with individual time trends	95% CI: -0.44 to -0.61 95% CI: -0.39 to -0.58 95% CI: -0.27 to -0.46 Results were statistically significant for the three model specifications. Results relate to pooled data for 9 medium size Australian cities (predominantly bus).	Booz Allen Hamilton (2000)	←←←
Melbourne	Cross-sectional (1964)	-0.05				Peak CBD work trips	Point elasticity estimates	Shepherd (1973)	
Australia	Time Series (1965-81)	-0.44 -0.16				National data (1965-81) Towns data (1969-80)	SD: +/- 0.12 (significant) SD: +/- 0.04 (significant)	Bly & Oldfield (1985)	←←
Melbourne (Australia)	Time Series (1955-71)	-0.7					Value is for 'road based' public transport.	Shepherd (1973), cited in Travers Morgan (1979)	
New Zealand	Time Series (1965-82)	-0.33				National Data only	SD: +/- 0.11 (significant)	Bly & Oldfield (1985)	←←
Adelaide	Time Series (1985-93)	-0.25 -0.18				Linear Model Log Model	SE: 0.12 SE: 0.08 Mostly bus mode. Some doubt over the veracity – no allowance for time trend.	Willis (1994)	←
Sydney (Australia)	Mode Choice Modelling (1981)				-0.10		The aggregate demand elasticities are a probability weighted average of individual elasticities.	Madan & Groehout (1987)	←←
Australia	Time Series (1977-89)			-0.67 -0.80			Pooled data (7 capitals). Aggregate model (7 capitals). Some doubt re robustness of these results (i.e. no service level or car ownership terms).	Gargett (1990)	←←

Appendix B: Public Transport Service Levels

B1. Introduction

This appendix provides an overview of the evidence from New Zealand, Australia and internationally on the effects of changes in service levels on public transport patronage (i.e. direct elasticities). It does not examine any cross-modal effects. Evidence is categorised into that specific to bus, rail and to public transport in general. Tables B1 to B6 summarise the ranges of elasticities by these modes.

Vehicle kilometres operated is generally used as a useful proxy measure of service levels and, although it is a fairly crude approximation as many factors make up the level of service, it is the most readily available aggregate measure.

Vehicle kilometres can reflect a number of factors that should be considered when examining the estimates including:

- Average frequency of service during a given period. For a fixed length route and fixed period of operation, frequency is directly proportional to vehicle-km.
- Length of day or week over which a service operates. Expanding the schedule on a fixed route to cover a longer period at the same frequency, e.g. in the evenings, would produce an increase in vehicle-km.
- Route length and network density. Increased vehicle-km (at a network level) may also reflect extensions of routes and/or additional routes, thus increasing accessibility (i.e. shorter walking distances).

Elasticities derived from network-wide vehicle-km statistics (the usual source) may thus encompass all three effects, although the average frequency of service during a given period is likely to be the predominant element.

Also, for service levels in particular, there is a 'cause and effect' relationship with patronage: increases in services tend to produce increases in patronage; but exogenous increases in patronage also tend to result in increases in services. This effect is difficult to exclude from the calculations, although before and after studies of specific service changes are thought likely to give the best results. Therefore, we have placed greater weight on our conclusions from before and after studies (where available).

B2. International Evidence

B2.1 Bus Service Levels

B2.1.1 Overall Estimates

Short Run (SR)

Table B1 summarises evidence on bus service elasticities, where service is measured in terms of vehicle kilometres. Although not explicitly stated in most cases, most of the values given would appear to be SR estimates based on the analytical technique applied, such as unlagged time series and before and after studies. Typical SR values found in the literature appear to range from 0.2 to 0.6. However, they tend to vary widely between studies. Some key results included:

- Balcombe et al. (2004) estimated an average SR value of 0.38 based on a review of the empirical literature (values ranged from 0.10 to 0.74).
- Dargay & Hanly (1999) estimated a short run value of 0.4 in their study of UK buses.
- In Europe, ISOTOPE (1996) estimated an overall value of 0.41.
- In Germany, Fitzroy & Smith (1998) derived a value of 0.65.
- de Rus (1990) found service-km elasticities ranged from 0.34 to 1.26 based on an analysis of 11 Spanish cities.
- In the US Pratt et al. (2000) observed much higher elasticities which typically ranged from 0.6 to 1.0 (although the time horizon was not specified).

Medium Run (MR) and Long Run (LR)
Dargay & Hanly (1999) and Balcombe et al. (2004) concluded that MR to LR estimates are approaching twice the SR estimates. This relationship is consistent with that found for fare levels, as noted by Dargay & Hanly in their analysis.

B2.1.2 Disaggregate Estimates

In general, although estimates varied from study to study, the following conclusions can be drawn:

- **Service frequency.** Elasticities for low frequency services were greater than for high frequency services. Cheung (cited in Booz Allen Hamilton 1998) found elasticities for lower frequency services were up to four times greater than high frequency services.
- **Trip purpose and time of day/week.** While no robust elasticity estimates were found for the various travel purposes, elasticities for the off-peak were generally found to be greater than the peak. For example, Lago et al. (1981a) found an average peak elasticity of 0.33 and an off-peak estimate of 0.63, compared to Rendle et al. (1978) who observed a peak estimate as low as 0.11 and a similar off-peak estimate of 0.62. Elasticities were also found to be lowest during the weekday inter-peak period, higher during the weekday peak and evening periods, and highest at weekends (Preston 1998, cited in Dargay & Hanly 1999). These differences in part reflect the service frequency effect (above), and in part the different traveller/trip purpose characteristics at the different periods.
- **City size.** Elasticities tend to be higher in larger centres. ISOTOPE (1996) reported that demand was more elastic in larger cities (0.49) than in smaller cities (0.33). The author attributes this to competition with other transport modes occurring in larger cities. The report also suggests that service is valued more highly in large cities because of higher income levels, and thus higher values of time.
- **Urban and suburban.** Allen (cited in Pratt et al. 2000) revealed a higher elasticity for local suburban services compared to urban services.

B2.2 Rail Service Levels

B2.2.1 Overall Estimates

Short Run (SR)

Our review of the international empirical evidence was inconclusive as to whether SR rail elasticity estimates are higher or lower than those for bus: there is considerable variation between studies (refer Table B2), which in part will reflect different trip lengths, average service frequencies, market segments, etc. Again, the majority of values quoted did not distinguish between the SR and LR, although most of the values appeared to be SR estimates based on the methodology applied. Some of the key findings included:

- A recent literature review undertaken by Balcombe et al. (2004) identified 3 SR values, with an average of 0.75 (range 0.65 to 0.90), and 2 values with unstated time period (0.33, 0.65). Most of these values related to medium-/long-distance services.
- One of the more rigorous studies undertaken in recent years was that by Asensio (2000) which examined panel data for 11 urban centres in Spain and estimated an elasticity of 0.53.
- Earlier work in London by Rendle et al. (1978) estimated a much lower elasticity of 0.10, which compares to more recent estimates for the Underground by London Transport (1997b) of 0.09.

Long Run (LR)

As for bus, MR to LR values for rail were of the order of 1.5 to 2 times higher than the SR estimates, although the empirical evidence available was rather limited.

B2.2.2 Disaggregate Estimates

While there is considerable empirical literature on overall service elasticities, there is relatively limited evidence on disaggregate elasticities, although many of these relationships are similar to bus, including:

- **Time of day.** Lago et al. (1981a) found that peak elasticities were generally around half the off-peak (i.e. estimated values of 0.10 and 0.25 respectively).
- **City size.** Asensio (2000) found that service elasticities for small cities were lower than for larger cities (i.e. 0.39 and 0.78 respectively), and similar to the findings for buses (Section B2.1.2). Asensio explains that this result implied that commuters in larger cities value quality improvements more than those in smaller urban areas: this may reflect higher incomes of users in the larger cities.

B2.3 Public Transport Service Levels

B2.3.1 Overall Estimates

Short Run (SR)

Table B3 details the results of our international review of service elasticities for public transport in general. A typical value appears to be around 0.5, however the results vary from study to study, ranging from around 0.2 to 0.8 or higher, which are not dissimilar to bus and rail. As for bus and rail, very few studies have explicitly defined the time horizon. We have therefore interpreted many of these results as SR based on the analytical technique used to derive these estimates. Balcombe et al. (2004) for example, observed a wide range of estimates from international studies, ranging from 0.26 to 1.14, while noting that the most reliable elasticities are probably in the range of 0.2 to 0.5. This compares to earlier empirical research by Bly & Oldfield (1985) which found typical values in the range 0.34 to 0.53.

Long Run (LR)
No evidence was found on LR values, but we have assumed a similar ratio to bus and rail, in the range from 1.5 to 2.0.

B2.3.2 Disaggregate Estimates

The findings and conclusions are in line with the bus and rail evidence:

- **Time of day.** Work trips were less elastic than non-work trips, and similarly peak demand appears more inelastic than off-peak demand.
- **Service frequency.** As for bus, the evidence indicates higher elasticity values at lower service frequencies.
- **Trip orientation.** Goodwin, cited in Lago et al. (1981a), found differences by type of service, with routes to the CBD being less elastic than suburban routes. This result may in part reflect different frequencies on the two types of routes.

B3. Australian and New Zealand Evidence

B3.1 Bus Service Levels

B3.1.1 Overall Estimates

Short Run (SR)
The results detailed in Table B4 show a considerable range of Australian and New Zealand bus elasticity values. A typical SR value appears to be around 0.5 to 0.6, which is generally comparable to the international evidence discussed in Section B2.

Australia. Earlier analysis in Australia by BTE (1977), Brown & Singleton (1981), and Shepherd (1973) found elasticity estimates towards the higher end of the range (i.e. values ranged from 0.6 to 1.2 depending on the study).

New Zealand. A number of studies undertaken in New Zealand have revealed results of a similar order of magnitude. Key findings included:

- Wallis & Yates (1990) undertook a time series analysis based on data from 7 urban centres and estimated average values ranging from 0.48 to 0.54, with a wider variation apparent between individual centres.
- Research by Galt & Eyre (1987) estimated values as high as 1.0 (passenger trips) and 1.3 (passenger-km) in their analysis of 26 urban centres throughout New Zealand.

B3.1.2 Disaggregate Estimates

Based on the relatively limited literature which examined the variation in elasticities by market segment, the following conclusions could be formulated:

- **Service frequency.** Based on a review of the empirical literature, Booz Allen Hamilton (1998) concluded elasticities are much lower than average for frequent services (i.e. 0.1 to 0.2 for services at least every 10 minutes), and generally increase for less frequent services (i.e. in the order of 0.8 for service frequencies worse than hourly).

- **Time of week.** Two studies (Wilson 2001, Booz Allen Hamilton 2001b) found that service elasticities for weekend travel were less than half those for weekday travel. However these results are contrary to UK evidence (Section B2.1.2), and also contrary to the general finding that elasticities are generally higher for lower frequency services.

B3.2 Rail Service Levels

B3.2.1 Overall Estimates

Short Run (SR)

Table B5 provides a summary of the relatively limited literature on the relationship between rail service kilometres and rail demand. While no explicit distinction has been made between the LR and SR, all the available results have been interpreted as SR. Rail service elasticities appear to be of a similar order to those for bus, and also range widely both within and between studies. Key findings included:

Australia. BTE (1977) and Shepherd (cited in Travers Morgan 1979) derived values for Australian cities that ranged widely from 0.2 to 1.2.

New Zealand. Two studies undertaken in New Zealand examined the overall impact of rail service changes on demand:

- Travers Morgan (1985) estimated SR to MR estimates ranging from 0.13 to 0.33 (depending on functional form).
- ARC (1997) estimated a service elasticity of 0.40 following their service expansion.

B3.2.2 Disaggregate Estimates

The only Australasian study that segmented the market in terms of its various attributes is SP research undertaken by Steer Davies Gleave (1993c) on the Sydney suburban rail market. CBD elasticities were found to be lower than non-CBD elasticities and peak travel was found to be less elastic than off-peak travel. Results by trip distance were inconclusive.

B3.3 Public Transport Service Levels

B3.3.1 Overall Estimates

As for bus and rail, public transport elasticities differed substantially between studies (refer Table B6).

Short Run (SR)

In Australia, Booz Allen Hamilton (2000) estimated a value of 0.22 using pooled data for 9 medium-sized Australian cities. This figure appears to be lower than values found in studies by Travers Morgan (1993), and by Willis (1994) which estimated values as high as 0.81.

Medium Run (MR) and Long Run (LR)

Some of the earlier empirical research by Bly & Oldfield (1985) estimated MR values for Australia and New Zealand from lagged time series data. Values ranged from 0.16 and 0.66 depending on the type of data. No other MR or LR estimates were identified.

B4. Conclusions

B4.1 Overall Estimates

The New Zealand, Australian and international evidence on overall service level elasticities shows a wide range, with SR values ranging as low as 0.1 and as high as 0.9 or even higher. This wide range in part reflects the wide range of circumstances examined, particularly in terms of base frequency levels.

Making allowance for base frequency levels, no strong evidence of significant differences exists in service elasticities for bus versus rail services. We therefore assume equal elasticities.

Based on typical New Zealand urban bus service frequencies (20-30 mins), we would recommend a SR service frequency central estimate of 0.35, with a typical range of 0.20 to 0.50.

These estimates are noted to vary broadly in proportion to the service frequency, for frequencies of up to about 1 hour.

For long-run estimates, the above service elasticities are expected to be approximately doubled.

B4.2 Disaggregate Estimates

The international evidence on disaggregated service level elasticities is somewhat limited, and that for New Zealand and Australia even more so. Based primarily on the international evidence, the following conclusions on disaggregated service elasticity values are drawn:

- Service elasticities vary broadly in proportion to base service frequencies (as above). Typical values would be 0.1 to 0.2 for 5-10 minute frequency services increasing to around 0.8 for hourly services, with lesser rates of increase for even less frequent services.
- Elasticities are substantially higher than average for shorter trips, particularly when walking is a ready alternative.

- Elasticities are typically lowest for peak trips, higher for weekday off-peak trips, and highest for weekend trips. (This result arises both from the frequency effect and the different market segments and trip purposes involved.) However some studies have reached different conclusions.
- The limited evidence indicates that elasticity values are largely independent of the magnitude of any service change or its direction (increase or decrease).

Table B1: Bus Service Levels – International Evidence

City/Country	Measure	Study Type and Period	Elasticity				Market Segment	Comments	Source	Rank
			Short Run	Med Run	Long Run	Not Stated				
Various – UK	Bus kms	Literature review	0.38		0.66			SR: 0.10 to 0.74, SD 0.135, 27 cases LR: 0.22 to 1.04, SD 0.275, 23 cases	Balcombe et al. (2004)	←←←
UK	Bus kms	Before and after	0.32 0.43				Increase in bus services Decrease in bus services	Values derived from TAS study.	TAS (2002)	←←
Houston and San Diego (US)	Bus kms	Cross sectional (1980-90)				0.71			Kain & Lui (1999)	←
London (UK)	Bus kms	Time Series (1971-82)	0.18					95% CI: 0.06 to 0.30	Fairhurst & Edwards (1996)	←
(Outside London) UK	Bus kms	Time Series (1971-86)	0.95					95% CI: 0.39 to 1.50 Paper noted that the most likely value for the rest of the UK (areas outside London) was 0.30.	Fairhurst & Edwards (1996)	←
Various	Bus kms	Literature review of quasi-experimental data				0.63	All Hours	SD: +/- 0.24 (3 cases)	Lago et al. (1981a)	←
Various	Bus kms	Literature review of non-experimental data				0.33 0.63 0.49	Peak Off-Peak All Hours	SD: +/- 0.18 (3 cases) SD: +/- 0.11 (3 cases) SD: +/- 0.31 (17 cases)	Lago et al. (1981a)	←
London (UK)	Bus kms	Time Series (1971-95)	 1.17 0.27 0.01 0.09				Segmentation by time period to capture variations in kms (1970-1977) (1977-1979) (1980-1986) (1987-1995)	 0.20 SE 0.22 SE 0.18 SE (i.e. not significant) 0.07 SE	London Transport (1997)	←←
Netherlands	Service kms	Before and after (<1995)				0.0 to 0.2 0.8 to 0.9	High Frequency (Weekend) Services (>1 bus per 30 mins) Low Frequency (Weekend) Services (<1 bus per hour)		Cheung, cited in Booz Allen Hamilton (1998)	←

Table B1: Bus Service Levels – International Evidence

City/Country	Measure	Study Type and Period	Elasticity				Market Segment	Comments	Source	Rank
			Short Run	Med Run	Long Run	Not Stated				
Spain	Service kms	Time Series (1980-88)		0.34 to 1.26				Based on data from 11 Spanish bus operators. Results (static model) were statistically significant for most operators.	De Rus (1990)	←←
Freiburg (Germany)	Service kms	Time Series (1969-95)		0.65				Elasticity value was significant. Reasonably well specified model.	Fitzroy & Smith (1998)	←
Freiburg (Germany)	Frequency	Time Series (1969-95)		0.56				Elasticity value was not significant. Reasonably well specified model.	Fitzroy & Smith (1998)	
Dallas (USA)	Service kms	Cross sectional (1985-86)				0.32	Urban		Allen, cited in Pratt et al. (2000)	←
						0.38	Suburban			
						0.36	Suburban Local			
Various	Service kms	Literature review				0.6 to 1.0		Author maintains that much broader variations have been reported including instances over 1.0.	Pratt et al. (2000)	←←
UK	Service kms	Literature review				0.40 to 0.54		Also estimated an elasticity of -0.6 for vehicle kms lost (based on 2 cases).	Goodwin & Williams (1985)	←
UK	Service kms	Time Series, with lagged model	0.45		0.80			Range of models using pooled county data. SR less than 1 year, LR 7+ years. LR values typically 1.5 to 2.0 times SR values. Shire county values around 1.5 to 2.0 times metropolitan values.	Dargay & Hanly (2002)	←←←
UK (Various English Counties)	Bus kms	Pooled Time Series, with lagged formulation (1985-96)	0.43		0.81			SR up to 1 year, LR 7+ years. Range of values from different models: metropolitan area values lower than shire values.	Dargay & Hanly (1999)	←←←
UK	Bus kms		0.38		0.58		Early Morning Peak	Dargay & Hanly note that the service elasticity estimates observed have wide confidence intervals so that some of the differences between time periods may not be statistically significant.	Preston (1998), cited in Dargay & Hanly (1999) and Balcombe et al. (2004)	←←
			0.17		0.30		Interpeak			
			0.35		1.95		Evening			
			0.52		0.67		Saturday			
			1.05		1.61		Sunday			
					0.13		All Periods			
Europe	Bus kms	Regression of data within the ISOTOPE database	0.33				Small Cities	SE: +/- 0.065	ISOTOPE (1996)	←←
			0.49				Large Cities	SE: +/- 0.037		
			0.41				All Cities			
Telford Shropshire (UK)	Bus kms	Before and after (1978)	0.29 to 0.37				Non-Shopping Trips	*Shopping trip result was not statistically difference from zero and the wrong sign.	Urquhart & Buchanan (1981)	←
			-0.06*				Shopping Trips			

Table B1: Bus Service Levels – International Evidence

City/Country	Measure	Study Type and Period	Elasticity				Market Segment	Comments	Source	Rank
			Short Run	Med Run	Long Run	Not Stated				
UK	Bus kms	Time Series (1966-76)	0.29 0.62 0.15 0.35				Weekday Off-Peak Peak Overall	SE: +/-0.06 SE: +/-0.16 SE: +/- 0.06 SE: +/-0.06 Weekday findings were obtained directly from the regression. Other findings were synthesised from the weekday and weekend results.	Rendle, Mack & Fairhurst (1978)	←←
UK	Bus kms	Time Series (1960-73)	0.62					Based on data from 16 urban bus operators in towns with population greater than 100,000.	Mullen (1975)	←
UK	Bus kms	Time Series (1977-83)	1.11				Adult	SE:0.22	McKenzie (1984)	←
Portland, USA	Bus kms	Time Series (1971-82)	0.51				System-wide effect	Author notes that at the route level the study found that the response delay to service level changes tends to be about two to three times longer for urban routes than suburban routes.	Kyte, cited in APTA (1991)	
UK	Bus kms	Time Series (1961-73) (1956-73)	0.74 0.90						Lowe (1978)	←
Gosport and Fareham (UK)	Bus kms	Before and after (1976-79)	0.55 0.81 0.60				Weekdays Weekends All Week		Layfield (1981)	←

Table B2: Rail Service Levels – International Evidence

City/Country	Measure	Study Type and Period	Elasticity				Market Segment	Comments	Source	Rank
			Short Run	Med Run	Long Run	Not Stated				
Various	Rail kms	Literature review	0.75			0.49		N/S: 0.33 to 0.65, SD 0.23 (2 cases) SR: 0.65 to 0.90, SD 0.13 (3 cases) SR estimates based on medium/long-distance services.	Balcombe et al. (2004)	←←
London (Underground)	Rail kms	Time Series (1971-1995)	0.09					0.07 SE	London Transport (1997b)	←
London (UK)	Rail kms	Time Series (1966-1976)	0.02 0.20 0.02 0.10				Weekday Peak Off-Peak Overall	SE: +/- 0.05 SE: +/- 0.10 SE: +/- 0.05 SE: +/- 0.10 Weekday findings were obtained directly from the regression analysis. Other findings were synthesised from the weekday result. Underground demand.	Rendle et al. (1978)	←
Spain	Rail kms	Panel data for 11 urban centers (1991-1995)	 0.53		 0.83	0.78 0.39	Large Cities Small Cities Overall	Results were statistically significant.	Asensio (2000)	←←←
Various	Rail kms	Literature review non-experimental data				0.10 0.25 0.55 0.31	Peak Off-Peak All Hours Average	SD: +/- 0.19 for the average.	Lago et al. (1981a)	←

Table B3: Public Transport Service Levels – International Evidence

City/Country	Measure	Study Type and Period	Elasticity				Market Segment	Comments	Source	Rank
			Short Run	Med Run	Long Run	Not Stated				
Various	Frequency Service kms	Literature review				0.50 0.60 to 1.0		Author notes a wide variation in elasticity estimates depending on demographic factors.	Pratt et al. (2000)	←←←
San Diego (USA)	Service kms	Time Series	0.75 to 0.85 0.65 0.72 1.01				Overall Radial routes to CBD Central city routes Suburban routes	Analysis over a 40-month period where services expanded 80%.	Goodwin et al., cited in Lago et al. (1981a)	←
Atlanta (USA)	Service kms	Time Series	0.30						Kemp, cited in Lago et al. (1981a)	←
Various	Service kms	Literature review				0.30 0.85 0.65 0.76 0.62 0.58 0.76	Atlanta San Diego (all routes) San Diego (est. routes) 17US Operators 12 British Operators 30 British Towns (work trips) 30 British Towns (non-work trips)	Most studies reviewed used Time Series data but some were inferred from cross-sectional data or were taken from Time Series demand studies that did not specifically focus on service changes.	Barton-Aschman Associates (1981), cited in Multi-Systems (1982)	←
Various	Service kms	Literature review	0.2 to 0.5			0.55 0.35 0.58 0.76 -0.5 to -0.6	Before and after studies Low frequency High frequency Holland – Work trips Holland – Non Work Service headway	Conclusions are with reference to the TRRL report and other studies.	Hopkin et al. (1988)	←←
Stockholm	Service kms	Time Series (1973-96)	0.29					Estimate was not significant.	Tegner et al. (1988)	←
Norway	Service kms	Analysis from the Norwegian Experiments						Various trial projects throughout Norway focused on improving public transport services. The trials showed that for a given public transport share of 10%, a fare reduction combined with more frequent services results in 40% new passengers on the routes concerned.	TOI Norway (1993)	

Table B3: Public Transport Service Levels – International Evidence

City/Country	Measure	Study Type and Period	Elasticity				Market Segment	Comments	Source	Rank
			Short Run	Med Run	Long Run	Not Stated				
Various	Service kms	Time Series (1965-82)	0.34 0.53				National Data Towns Data	SD: +/- 0.04 SD: +/- 0.03 Lagged regression – values could be interpreted as medium run. Extension of earlier work by TRRL.	Bly & Oldfield (1985)	←←←
Netherlands	Service kms					0.58 0.76	Work trips Non-Work trips		Author unknown, cited in Travers Morgan (1990a)	←
Various	Service kms	Review – Time Series	0.2 to 1.2				Overall	Analysed data from various studies across the world and concluded that demand is slightly more responsive to changes in service levels than to changes in fares. Report notes the difficulty in separating cause and effect especially in Time Series models. Author concludes that elasticities in the range 0.2 to 0.5 are probably most reliable.	TRRL (1980)	←←
		Review – Cross-sectional	0.6 to 1.4							
		Review – Before and After	0.2 to 1.0							
			0.55 0.35				Low Frequency High Frequency			
Various	Service kms	Literature review				0.26 to 1.14		General comment based on the literature.	Balcombe et al. (2004)	←←

Table B4: Bus Service Levels – Australian and New Zealand Evidence

City/Country	Measure	Study Type and Period	Elasticity				Market Segment	Comments	Source	Rank
			Short Run	Med Run	Long Run	Not Stated				
Auckland (New Zealand)	Bus kms	Discussions with operators (1988)				0.5 to 0.6		Values are largely anecdotal. Evidence is based on service re-design since 1976.	Travers Morgan (1988)	←
Christchurch (New Zealand)	Bus kms	Before and after study (<1988)	0.94					Estimate is based on doubling inter-peak frequency on the university/ airport route. Surveys were 3 months before and 3 months after the change.	Travers Morgan (1988)	←
Australian (6 capital cities)	Bus kms/capita	Pooled Time Series and cross-sectional (1955/56 to 1973/74)	0.63					Value of 1.0 derived for aggregate data (range from 0.34 to 1.11 in individual cities). Values should be treated with caution, i.e. cause and effect.	BTE (1977)	←
New Zealand	Bus kms/ capita	Cross-sectional (1981)				1.00 1.32	Passenger trips Passenger kms	Based on analysis of 26 urban centres. Estimates were statistically significant. Point elasticity estimates. Values should be treated with caution – mixed cause and effect.	Galt & Eyre (1987)	←
Wanganui (New Zealand)	Bus kms	Time Series (1978-85)	0.70					Greyhound Buses Wanganui. Result was statistically significant. The study sought to identify the medium term effect of real fare changes by developing a lagged elasticity which is slightly higher (in absolute terms) than the immediate elasticity.	Galt & Eyre (1987)	←←
Christchurch (New Zealand)	Bus kms	Time Series (1975-89)	0.4 to 0.5					Authors urge caution when using this estimate given the nature of the service changes over the period.	Travers Morgan (1989)	←
Auckland (New Zealand)	Bus kms	Time Series (1967-78)	0.67					Estimate is subject to particular uncertainty given the service changes involved.	Pringle (1979)	←
Melbourne (Australia)	Bus kms	Time Series (1972-76)	1.23 1.18 0.83				Government buses Private buses Tram	Likely to be mixed cause and effect.	Singleton (1978); Brown & Singleton (1981)	←
Christchurch (New Zealand)	Frequency	Before and after (2000)	0.58 0.17				Weekdays Sunday	Point elasticity estimates. Results 6-8 months after frequency increases. Analysis of Lyttelton service found a 19% and 8% increase in patronage (i.e. weekday and Sunday respectively) based on a frequency increase.	Booz Allen Hamilton (2001b)	←
New Zealand	Frequency	Literature review	0.1-0.2 0.8				High frequency (at least every 10 mins) Low frequency (less than hourly)		Booz Allen Hamilton (1998)	←←←

Table B4: Bus Service Levels – Australian and New Zealand Evidence

City/Country	Measure	Study Type and Period	Elasticity				Market Segment	Comments	Source	Rank
			Short Run	Med Run	Long Run	Not Stated				
Melbourne (Australia)	Bus kms	Time Series (1955-71)	1.30					Estimate was for bus and tram.	Shepherd (1973), cited in Travers Morgan (1979)	
New Zealand	Bus kms	Time Series (1974/75 to 1988/89)	0.54 0.48				Log Model Form First Difference Model Form	Based on data from 7 urban centres. The results of both models were not significant,i.e. SE 0.47 and 0.51 for the log and first difference models respectively.	Wallis & Yates (1990) Travers Morgan (1990a)	←←
Adelaide (Australia)	Bus kms	Before and after (1999/00)	0.46 0.49 0.20				Weekday Saturday Sunday	Weekday range: -2.59 to 1.90 Saturday range: -0.34 to 1.34 Sunday range: 0.16 to 1.34 Service frequency increases on a range of routes. Elasticity estimates for ticketing data for 6 months after the change compared to the same period 12 months earlier.	Wilson (2001)	←

Table B5: Rail Service Levels – Australian and New Zealand Experience

City/Country	Measure	Study Type and Period	Elasticity				Market Segment	Comments	Source	Rank
			Short Run	Med Run	Long Run	Not Stated				
Wellington	Rail kms	Time Series (1968/69 to 1983/84)	0.13 0.33				Log Form First Difference	SE: 0.14 Log model SE: 0.17 First difference model	Travers Morgan (1985)	←←
Brisbane (Australia)	Rail kms	Time Series (1955-71)	0.5						Shepherd (1973), cited in Travers Morgan (1979)	
Adelaide (Australia)	Rail kms	Time Series (1955-71)	1.2						Shepherd (1973), cited in Travers Morgan (1979)	
Sydney (Australia)	Rail kms	Stated preference (1992)	0.11 0.18 0.08 0.12 0.11 0.15 0.16 0.18 0.03 0.06 0.08 0.11				Short CBD peak Short CBD Off-Peak Short Non-CBD peak Short Non-CBD Off-Peak Medium CBD peak Medium CBD Off-Peak Medium Non-CBD peak Medium Non-CBD Off-Peak Long CBD peak Long CBD Off-Peak Long Non-CBD peak Long Non-CBD Off-Peak		Steer Davies Gleave (1993c)	←
Auckland	Frequency	Before and after (1994-95)	0.4					Analysis of the 1994/95 rail service expansion.	ARC (1997)	←←
Australia (6 Capital Cities)	Rail kms/ capita	Pooled Time Series and cross-sectional (1955/56-1973/74)		1.10			Average estimate	Value 0.21 derived from aggregate data and values of 0.44 to 1.07 in individual cities. Values to be treated with caution: mixed cause and effect.	BTE (1977)	←

Table B6: Public Transport Service Levels – Australian and New Zealand Experience

City/Country	Measure	Study Type and Period	Elasticity				Market Segment	Comments	Source	Rank
			Short Run	Med Run	Long Run	Not Stated				
Australia	Service kms	Time Series (1966-82)		0.16 0.66			National Data Towns Data	SD: +/- 0.28 (not significant) SD: +/- 0.18 (significant) Lagged regression – values interpreted as medium run estimates. Extension of earlier work by TRRL. Values are likely to be over-estimates (i.e. problem of cause and effect).	Bly & Oldfield (1985)	←
New Zealand	Service kms	Time Series (1966-82)		0.19			National Data	SD: +/- 0.05 Mostly bus mode. Lagged regression – values interpreted as medium run estimates. Extension of earlier work by TRRL. Values are likely to be over-estimates (i.e. problem of cause and effect).	Bly & Oldfield (1985)	←
Adelaide (Australia)	Service kms	Time Series (1985-93)	0.81 0.72				Linear Model Form Log Model Model Form	SE: 0.35 SE: 0.29 Mostly bus mode. Results were statistically significant. Author noted the likely problem of separating 'cause and effect' in the model. Some doubt on veracity as no allowance for the time trend term.	Willis (1994)	←
Australia (9 cities)	Service kms	Pooled Time Series (1984/85 to 1998/99)	0.22				Aggregate model	95% CI: range 0.22 to 0.25 Result related to pooled data for 9 medium size Australian cities (predominantly bus mode). Based on a range of model forms. Results were statistically significant and models were well specified.	Booz Allen Hamilton (2000)	←←
Christchurch (New Zealand)	Service kms	Recommended estimates based on the empirical literature				0.5 0.4 0.8 0.9 1.5 0.3 to 0.4 0.5 to 0.6	Overall Peak Interpeak Saturday Sunday High Frequency Routes Low Frequency Routes	Peak work: 30% switches from car driver. Off-Peak: 15% switches from car driver.	Travers Morgan (1993a)	←

Appendix C: Public Transport In-Vehicle Time

C1. Introduction

The amount of time spent travelling in a vehicle is an important service attribute which impacts on the level of public transport demand. This appendix provides an overview of the evidence from New Zealand, Australia and internationally, on the effects of changes in public transport in-vehicle time on public transport demand. It does not examine the cross-modal effects. Tables C1 and C2 summarise the results of the review.

C2. International Evidence

C2.1 Overall Estimates

Both more recent and earlier international evidence (Table C1) in relation to in-vehicle time elasticities is very limited. Probably one of the most comprehensive reviews is the earlier work by Lago et al. (1981b), which found values ranged from around –0.10 to –0.80 depending on the mode, market segment and study type. Many of the differences in results for the different market segments were found to be not statistically significant.

C2.2 Disaggregate Estimates

The results available for the various market segments were also very limited and often such that no firm conclusions could be drawn. Some of the primary observations included:

- **Time of day/trip purpose.** The evidence is inconclusive with half the studies showing peak time to be more sensitive than off-peak and half showing off-peak to be more sensitive than the peak. A study by Charles River Associates (1997) in Boston found that work trips were less sensitive to changes in in-vehicle time than shopping trips, although McFadden (1974, cited in Gomez-Ibanez et al. 1999) observed a relatively high elasticity for work trips.
- **Trip distance.** British Rail (1994), in its review of UK evidence, found that long trips were more elastic than short trips.
- **Differences between modes.** There appears to be some variation between modes, although limited evidence precludes us from drawing any substantive conclusions. Recently the VTPI (2002) suggested an in-vehicle time elasticity of –0.58 for urban buses. This compares to rail in-vehicle time elasticities ranging from –0.63 to –0.70 suggested by Mackett & Nash (1991) and Mackett & Bird (1989, cited in Balcombe et al. 2004). Likewise, Steer Davies Gleave (1999) and Small & Winston (1999, both cited in Balcombe et al. 2004) estimated values broadly similar for rail services.

C3. Australian and New Zealand Evidence

C3.1 Overall Estimates

Australian evidence is limited, with no evidence in New Zealand (Table C2), on patronage response to changes in in-vehicle time. Australian values differed substantially between studies with most values in the range from –0.10 to –0.50. Often it was unclear whether the elasticities were SR or LR values.

C3.2 Disaggregate Estimates

Most of the evidence (albeit limited) has focused on work trip demand, particularly travel to the CBD. Many of the estimates are of the order of –0.10 to –0.20. Steer Davies Gleave (1993c) provided a comprehensive stated preference study of rail demand with respect to in-vehicle time in Sydney. The market was segmented according to trip length, time of day and trip orientation (i.e. CBD versus non-CBD). Peak demand was found to be less elastic than off-peak demand for all market segments. Demand for CBD trips was generally less elastic than for non-CBD trips. No marked differences were observed by trip length.

C4. Conclusions

C4.1 Overall Estimates

Very limited evidence was available in New Zealand and internationally that examined the elasticity of public transport demand with respect to public transport in-vehicle time.

Based on the evidence available, the following **short-run** values are suggested for New Zealand urban centres:

• **Bus**	- central estimate	–0.30
	- typical range	–0.10 to –0.50
• **Rail**	- central estimate	–0.50
	- typical range	–0.30 to –0.70

Very limited information is available on the relationship between short-run and long-run values. What is available indicates that **long-run** values are 1.5 times to 2.0 times the short-run values (which is consistent with the findings for fares and service levels).

C4.2 Disaggregate Estimates

Based on the very limited systematic information available, we draw the following conclusions on in-vehicle time elasticities at a disaggregated level:

- **Trip purpose/time period**. While evidence is inconclusive, overall peak period demand appears to be less elastic than off-peak demand.

- **Trip distance.** Based on limited evidence, longer trips appear to be more elastic than short trips. (This would be consistent with the higher proportion of total travel time spent in-vehicle on longer trips.)
- **CBD versus non-CBD.** CBD trips appear to be less elastic than non-CBD trips (perhaps reflecting the difficulties of car use for CBD trips).

Table C1: In-vehicle Time – International Evidence

City/Country	Mode	Study Type and Period	Elasticity			Market Segment	Comments	Source	Rank
			Short Run	Long Run	Not Stated				
Various	Bus	Literature Review of Quasi-Experimental Data			-0.29 -0.83	Peak Off-Peak	SD: +/- 0.13 (9 cases) (1 case) Point elasticities	Lago et al. (1981b)	←
Various	Bus	Literature Review of Non-Experimental Data			-0.68 -0.12	Peak Off-Peak	SD: +/- 0.32 (7 cases) (1 case) Point elasticities	Lago et al. (1981b)	←
Various	Rail	Literature Review of Non-Experimental Data			-0.70	Peak	SD: +/- 0.10 (2 cases) (1 case) Point elasticities	Lago et al. (1981b)	←
Various	Rail	Literature Review of Non-Experimental Data			-0.59	Commuter Rail All Hours	SD: +/- 0.28 (9 cases) (1 case) Point elasticities	Lago et al. (1981b)	←
Various	Public Transport (Bus and Rapid Rail)	Literature Review of Non-Experimental Data			-0.30 -0.27	Peak All hours	SD: +/- 0.10 (2 cases) (1 case) Point elasticities	Lago et al. (1981b)	←
Baltimore (USA)	Public Transport	Cross-sectional			-0.37	Peak		Brand & Benham (nd)	←
SE England (UK)	Rail	Transportation Model			-0.63			Mackett (1989), cited in Banister et al. (nd)	←
Stockholm (Sweden)	Public Transport	Transportation Model (1986/87)			-0.31 -0.36 -0.58 -0.58	Peak Trips Off-Peak Trips Peak kms Off-Peak kms		Algers et al. (1995)	←←
San Francisco (USA)	Rail and Bus	Mode Choice Model			-0.60	Work Trips		McFadden (1974), cited in Gomez-Ibanez et al. (1999)	←
USA?	Bus and Rail				-0.60		-0.58 for urban bus, -0.86 for urban rail.	Small & Winston (1999), cited in VTPI (VTPI) (2002)	←←
Boston	Public Transport	Cross Sectional 1963/64			-0.39 -0.59	Work trips Shopping trips	Shopping trips include both line-haul IVT and transit access time.	Charles River Associates, cited in Kemp (1974), Kemp (1973)	←←
West Yorkshire (UK)	Rail				-0.42		Reference to travel on local rail services.	Preston (1987), cited in VTPI (VTPI) ((2002)	←←

Table C1: In-vehicle Time – International Evidence

City/Country	Mode	Study Type and Period	Elasticity			Market Segment	Comments	Source	Rank
			Short Run	Long Run	Not Stated				
West Yorkshire (UK)	Rail				-0.42		Reference to travel on local rail services.	Preston (1987), cited in Victoria Transport Policy Institute (VTPI) ((2002)	←←
Various	Bus				-0.58			Victoria Transport Policy Institute (2002)	←←
London	Rail	Time Series (1966-71)	-0.9 -0.5			Long trips (Commuter) Short trips (Commuter)		Unknown author, cited in British Rail (1994)	
UK	Rail				-0.60 to -0.80			Steer Davis Gleave (1999), cited in Balcombe et al. (2004)	←
SE England (UK)	Rail		-0.74	-0.84	-0.63 to -0.70	Overall	SR: SD 0.37 (6 cases) LR: SD 0.41 (6 cases) Also estimated a value of -0.54 for the medium term.	Mackett & Nash (1991), Mackett & Bird (1989), cited in Balcombe et al. (2004)	←

Table C2: In-vehicle Time – Australian and New Zealand Evidence

City/Country	Mode	Study Type and Period	Elasticity			Market Segment	Comments	Source	Rank
			Short Run	Long Run	Not Stated				
Melbourne (Australia)	Public Transport	Cross-sectional (1964)			-0.12	Peak CBD work trips	Total travel time	Shepherd (1972)	←
Australia	Public Transport	Cross-sectional			-0.17		Total travel time elasticity Point elasticity	Smith (1975), cited in Travers Morgan (1979)	←
Perth (Australia)	Public Transport	Cross-sectional			-0.30	CBD work trips		Shepherd (1973), cited in Travers Morgan (1979)	
Sydney (Australia)	Rail	Cross-sectional			-0.28	Work trips for northern suburbs residents	A total travel time elasticity of -0.37 was also estimated.	Hensher (1972), cited in Travers Morgan (1979)	
Australia	Public Transport	Literature Review	-0.30 to -0.50					Bray & Ass. (1995)	←
Sydney (Australia)	Rail Bus	Mode Choice Experiment			-0.42 -0.60	Commuter Trips Commuter Trips		Hensher (1986), cited in Industry Commission (1994)	←
Sydney (Australia)	Public Transport	Cross sectional mode choice model			-0.11	Work Trips	This study updates earlier work undertaken by the authors that estimated a similar value of -0.11.	Madan & Groenhout (1987)	←←
Sydney Australia)	Rail	Stated Preference	-0.09 -0.15 -0.16 -0.22 -0.13 -0.16 -0.17 -0.20 -0.08 -0.10 -0.19 -0.26			Short CBD Peak Short CBD Off-Peak Short NonCBD Peak Short NonCBD Off-Peak Med CBD Peak Med CBD Off-Peak Med NonCBD Peak Med NonCBD Off-Peak Long CBD Peak Long CBD Off-Peak Long NonCBD Peak Long NonCBD Off-Peak	Authors note that values are short- to medium-run estimates.	Steer Davis Gleave (1993c)	←

Appendix D: Public Transport Reliability

D1. Introduction

This appendix details the international evidence on the elasticity of public transport demand with respect to changes in public transport reliability. Table D1 summarises that evidence. Reliability generally refers to the requirement for the services to run on schedule. It impinges on travel time through its effect on waiting times and arrival times, affecting both the time spent waiting for a service and the way this time is perceived. Qualitative and attitudinal studies of travel choice behaviour have found that the punctuality, reliability and dependability of a transport system are rated by users as a very important feature, affecting both their perceptions and levels of use for different transport modes.

D2. International Evidence

In spite of its importance, public transport demand elasticities (or other quantitative estimates) with respect to service reliability are very limited and often only qualitative estimates of passenger response to reliability have been made. Generally the two approaches to quantitative estimation are:

- Lost kilometres; and
- Variability in travel or arrival times.

Aside from quantitative methods of estimation, often the importance of reliability is pointed out by various attitudinal surveys. Paine (1967, cited in Lago et al. 1981b), CILT (1985) and Bates et al. (2001), for example, provide evidence that public transport users attach great importance to service reliability, often more than travel time and cost.

D2.1 Lost Kilometres

Bly (1976) developed a theoretical model for estimating the effects of random service cuts on passenger waiting times. This model indicated that, for high frequencies, the percentage increase on average waiting times is about twice the percentage of bus services not operated; while for low frequencies this factor increases to three or more (i.e. a 10% random service cut will increase waiting times by around 20% for frequent services, 30% or more for less frequent services). Further the 'excess' waiting time experienced by passengers is likely to be valued at 2-3 times ordinary waiting time, reflecting the anxiety and annoyance caused. Webster (1977) reviewed the work by Bly (1976) and concluded that, if excess waiting time due to irregularities in public transport service is twice the value of normal waiting time, then the demand elasticity:

> *would be expected to be four or more times that of normal bus kilometres elasticity, and this seems to be in keeping with the importance attached to the regularity and reliability by both operators and the public, as indicated in attitudinal surveys.*

D2.2 Variability in Travel Times

Bates et al. (2001) undertook one of the most comprehensive studies of the impacts of variability in travel times. The study noted that reliability is often quantified by estimating the coefficients of an appropriate (indirect) utility function in a similar way to valuing time savings. It can be characterised by a single variable such as the standard deviation of travel time. The results suggested that values around 2.0 (reliability ratio) are plausible, although values above 2 are unlikely. This implies that a reduction in the standard deviation of 1 minute would be perceived as equivalent to an increase in the mean travel time of 2 minutes. Similarly, Atkins & Polak (cited in Balcombe et al. 2004) found that the standard deviation (reliability ratio) generally lies in the range of 0.8 to 2.3, depending on the market segment.

D3. Australian and New Zealand Evidence

The only relevant study found in Australia was a Sydney before-and-after suburban rail study undertaken by Gallagher (1985). This estimated an elasticity of 0.77 with respect to the percentage of services that are no more than 5 minutes late. It is not readily possible to compare this with the 'reliability ratio' approach adopted by Bates et al. (2001).

No relevant New Zealand studies were identified.

D4. Conclusions

Based on the limited information available, our conclusions on the two separate aspects of 'reliability' are as follows:

- In the general case of irregular services, the elasticity with respect to the standard deviation of arrival times is estimated at around twice the elasticity for in-vehicle time, i.e. in the range –0.6 to –1.0.
- In the case of 'missed trips', the demand elasticity with respect to the change in vehicle kilometres would be 4 to 5 times that for a scheduled service adjustment: this gives an effective elasticity in the order of 1.5 to 2.0.

Table D1: Reliability Impacts – International Evidence

City/Country	Mode	Study Type and Period	Elasticity	Comments	Source	Rank
UK	Bus	Review of revealed preference data from various UK bus operators	-0.15 (lost mileage)	Examined various demand drivers. Found 0.15% of passengers were lost for each 1% loss in bus mileage.	TAS (2002), cited in Bus Industry Monitor (1998)	←←
UK	Public Transport	Various stated preference studies		Review of the literature revealed all of the studies used stated preference techniques because of the difficulties in isolating and observing the actual changes in service reliability. The authors recommend that, for business and leisure passengers, a given level of reliability should be expressed as average lateness and converted to equivalent journey time by multiplying by 2.5. For commuters the mean delay should be multiplied by 1.25 and the standard deviation of delays by 3.2.	British Rail (1994)	←←
UK	Public Transport			Study suggests that an even greater effect occurs if vehicle kilometres are lost from an initially reliable service: on short headway services, if 10% of the buses are cut randomly from the service average passenger waiting time will increase by 20%, suggesting that service loss due to unreliability will have twice the effect of planned cuts, and an even larger effect is predicted at long headways. The effect on patronage is likely to be more pronounced since the uncertainty about when the next vehicle will arrive will cause considerable anxiety and annoyance to passengers. Waiting as a result of a 'missed' or late service is likely to be valued at 2-3 times ordinary waiting time.	TRL (1980)	←←
UK	Public Transport	Literature review		Authors found no example of a study which had directly measured the effect of changes in reliability on passenger demand, though a number of indirect methods had been used including: • A Paris study set the formula for average waiting time equal to three quarters of the average headway, thus allowing for some effect of irregularity. • One set of elasticities for reductions in delay (improvements in reliability) was sourced from London Transport in the 1970s. It applied different headway elasticities for scheduled kilometres and for lost kilometres (i.e. scheduled but not run). London Transport found that an unplanned service elasticity is 33% greater than the planned service elasticity. • Bly (1976) considered the effect of randomly missing buses on passenger waiting times over a wide range of headways – the effect was estimated to be twice that of planned cuts for short headway services and up to three times for very infrequent services.	TRRL (1980)	←
UK	Public Transport	Household survey of stated intentions		Survey results found that the majority of respondents (68%) for lower socio-economic groups would travel more compared to 53% for higher socio-economic groups.	CILT (1985)	←
Various	Public Transport	Attitudinal Surveys		Provides evidence that transit users attach greater importance to transit reliability than to travel time and trip cost.	Paine (1967), cited in Lago et al. (1981b)	←

Table D1: Reliability Impacts – International Evidence

City/Country	Mode	Study Type and Period	Elasticity	Comments	Source	Rank
UK	Bus			In reviewing earlier work by Bly (1976), Webster concluded that, if excess waiting time (due to irregularities in transit service) is twice the value of normal waiting time, then the demand elasticity: *"would be expected to be four or more times that of the normal bus kilometres elasticity, and this seems in keeping with the importance attached to regularity and reliability by both operators and the public, as indicated in attitude surveys".*	TRRL (1980), Lago et al. (1981b)	←←
Various	Public Transport	Literature review of valuation techniques		A key finding of this work was that punctuality is valued highly by travellers. According to the authors this finding is in line with the supporting qualitative research. The author noted that quantifying reliability is often carried out by estimating the coefficients of an appropriate (indirect) utility function in a similar way to valuing time savings. It can be characterised by a single variable such as the standard deviation of travel time. The results suggested values around 2.0 (reliability ratio*) are plausible, although values above 2 are unlikely. This implies that a reduction in the standard deviation of 1 minute would be compensated by an increase in the mean travel time of 2 minutes. For example, a typical urban journey might take 30 minutes, so that the traveller would be indifferent between a journey having a mean time of 30 minutes and a standard deviation of 6 minutes, and one having a mean time of 32 minutes with a standard deviation of 5 minutes. *Author notes that the reliability ratio, developed by Black & Towriss, is defined as the relative valuation of "reliability" and travel time.	Bates et al. (2001)	←
Various				This study investigated the valuation of bus reliability for in-vehicle time and waiting time and found that the reliability ratio was approximately 1.6 and 1.3 respectively. Author notes this effect is lower than rail which typically ranges between 2 and 10 (although values above 2 do not seem credible).	Rohr & Polak (1998), cited in Bates et al. (2001)	←
New York (USA)	Light Rail Transit			Reliability was one of the key factors used in the ridership analysis of a people mover linking New York airports with Manhattan. Models were estimated for a number of market segments using trade-off analysis methods. Reliability estimates were generally found to be high – delay time was valued at 10 times the line haul average. The ratio ranged from as high as 23 to 1 for travellers using taxis and cars to a low 3 to 1 for those currently using public transit. The author comments that the weights may be affected by the high cost of missing a flight. (This situation is not typical for urban public transport.)	Charles River Associates (1995), cited in Charles River Associates (1997)	←

Table D1: Reliability Impacts – International Evidence

City/Country	Mode	Study Type and Period	Elasticity	Comments	Source	Rank
UK	Bus	Literature review		Study gives values for bus reliability relative to average in-vehicle time by time period and journey purpose: Journey to work: 1.4 (IVT) and 2.0 (SD) Shopping: 0.8 (IVT), 0.8 (SD) Other: 1.3 (IVT), 2.3 (SD) Peak: 1.4 (IVT), 1.8 (SD) Off-Peak: 0.9 (IVT), 1.2 (SD)	Atkins & Polak (1997), cited in Balcombe et al. (2004)	←
UK	Bus	Literature review		Author examined a study in Edinburgh that revealed passenger increases recorded on corridors with bus priority appear to have been achieved by improved reliability. Author concludes that measuring the elasticity of demand to changes in reliability is complex and that there is very limited data available. Their analysis of TfL data demonstrated that reliability has a very significant impact on patronage and revenue. TAS also examined customer perceptions of reliability in Sheffield and Hyndburn, and found that majority of passengers believed that late running and operating failure was higher than it actually was. TAS also found that telling customers that the service was reliable did increase confidence in the reliability of service, until it was disproved by the weight of personal experience.	TAS (2002)	←
Sydney	Rail	Before and after study	0.77 (%services<= 5 mins late)	Part of a suburban rail study that examined the determinants of rail patronage including 'on-time running'. On-time running was referred to as the percentage of trains in the metropolitan area no more than 5 minutes late. The elasticity value was found to have a statistical influence on patronage which was both immediate and sustained for several subsequent periods. 95% CI: 0.34 to 1.20	Gallagher (1985)	←←
USA	Public Transport	Literature review		Attitudinal surveys of commuters in Baltimore and Philadelphia revealed "arrival at intended time" to be the second most important attribute for work trips. Similar surveys in Boston and Chicago placed "arrival at intended time" above travel time, waiting time and cost measures. For non-work trips reliability was judged not as important, although it was ranked eighth.	Golob et al. (1970) and Paine (1967), cited in Pratt et al. (2000)	←
Various				Author concludes that no measure of reliability has achieved statistical significance..., even though some...have involved considerable sophistication and effort.	Small (1992), cited in Industry Commission (1994)	←

Appendix E: Public Transport Generalised Costs

E1. Introduction

This Appendix E sets out the evidence from the international literature on the direct elasticity of public transport demand with respect to the total 'generalised costs' of the trip.

As noted in Chapter 2, transport modellers have developed various 'generalised cost' (or generalised time) formulations that combine the weighted values of public transport in-vehicle time, wait time, walk time and fares. This measure reflects the full generalised cost of travel. We note, however, that the literature often reports only the partial effect such as total time or monetary cost. The distinctions between generalised cost, generalised time, and the individual components of total time and cost have therefore been made where possible.

The appendix focuses on situations where generalised cost elasticities have been derived directly, rather than calculated from individual component elasticities. No such estimates were identified for Australia or New Zealand.

E2. International Evidence

Table E1 presents a summary of the international evidence on generalised cost elasticities for public transport. Relatively few studies have estimated values directly; while other studies have derived values from component elasticities based on the ratio of the component cost to the total generalised cost.

In terms of the studies which derived generalised cost estimates more-or-less directly:

- A number of early US modelling studies derived aggregate values in the range –0.55 to –1.29. Some evidence indicated that rail elasticities were greater than bus elasticities; but evidence on relative values for work and non-work trips was inconclusive.
- A number of early UK studies (cited in Oldfield 1974) gave values in the range –0.67 to –2.2, mostly for bus travel. The one study that attempted to estimate disaggregated values found that peak elasticities were slightly greater than off-peak values.
- The 1986 UK study (Preston & Nash 1986, cited in British Rail 1994) estimated rail demand elasticities in the range –1.0 to –1.8.
- The 1998 Paris study (Gunn et al. 1998) derived estimates of –0.60 and –1.32.
- Most of the other studies included in Table E1 estimated generalised cost elasticities indirectly from the component elasticities, rather than directly.

While many cases are unclear, we have assumed that the elasticity estimates given in Table E1 are generally short run (or possibly medium run).

E3. Conclusions

The weight of the direct evidence on public transport generalised cost elasticities is that overall values (short/medium run) are in the range –0.6 to –1.8. Other indirect evidence from the individual component elasticities would indicate values towards the middle of this range, say –0.9 to –1.5.

There is insufficient direct evidence on generalised cost elasticities to warrant any disaggregation of these values.

The above generalised cost values are not recommended for use directly. Chapter 4 of the report discusses in more detail application of the generalised cost approach in assessing changes in demand.

Table E1: Generalised Cost Elasticities – International Evidence

City/Country	Measure	Method	Elasticity			Comments	Source	Rank
			Short Run	Long Run	Not Specified			
UK	Generalised cost	Stated preference			-0.5 to -1.6 -0.5 to -1.7 -0.7 to -2.0	Bus Underground Rail Figures relate to medium-income group. Elasticities were also estimated for low and high income groups: results showed that elasticities were lower for low income groups relative to high income groups. Elasticities also found to be much lower for commuter travel than other travel.	Halcrow Fox et al. (1993a), cited in Balcombe et al. (2004)	←←
Tyne and Wear UK	Generalised cost				-1.89	Average bus estimate.	Balcombe & Astrope (1995)	←←
	Generalised cost	Literature review of 10 different sources			-0.5 to -1.5	Bus travel. This is based on the assumption that the bus fare is generally between 25% and 33% of the total generalised cost.	Oldfield (1974)	←←
London	Generalised cost	Time Series (1965-71)			-0.67	SE: +/- 0.06 Bus travel Author notes that this estimate is particularly sensitive to car licence availability. If the car licence term were omitted from the model, an elasticity of demand relative to the generalised cost emerged as -1.0.	Thompson, cited in Oldfield (1974)	←←
UK	Generalised cost				-2.2 -1.9	Peak Off-Peak	Buckles, cited in Oldfield (1974)	←←
London	Generalised cost	Time Series (1954-70)			-1.1	Author notes that total generalised cost is about three times the fare elasticity.	Goodwin, cited in Oldfield (1974)	←←
UK	Generalised cost	Transport modelling			-1.2	Bus passengers	Tulpule, cited in Oldfield (1974)	←←
Various	Generalised cost					Author concludes that generalised cost elasticities are generally not available, but can be determined by making a couple of assumptions. For example, a reasonable assumption might be to take the price elasticity of demand for urban buses to be of the order of -0.4. For some users bus fares may constitute half the generalised cost (the remainder being mainly time-related). As such, the generalised cost elasticity is -0.8.	Halcrow Fox (1993b)	←

Table E1: Generalised Cost Elasticities – International Evidence

City/Country	Measure	Method	Elasticity			Comments	Source	Rank
			Short Run	Long Run	Not Specified			
Paris	Total travel time and cost	Transportation modelling			-0.44 -0.16	Travel time (trips) Travel cost (trips) This equates to a total generalised cost elasticity of -0.60.	Gunn et al. (1998)	←
					-0.97 -0.35	Travel time (IVT) Travel cost (IVT) This equates to a total generalised cost elasticity of -1.32.		
West Yorkshire UK	Travel time	Transport modelling			-1.0	Rail demand – the average elasticities implied from the model-included -0.8 (fare); -0.4 (in vehicle-time) and -0.6 (walk and wait time). This equates to a total generalised cost elasticity of -1.80.	Preston & Nash (1986), cited in British Rail (1994)	←
San Francisco	Total travel time and cost	Mode choice modelling			-0.60 -0.58	Work trip demand Bus time Bus cost This equates to a total generalised cost elasticity of -1.18.	McFadden (1974), cited in Gomez-Ibanez et al. (1999)	←
					-0.60 -0.86	Rail time Rail cost This equates to a total generalised cost elasticity of -1.46.		
USA	Travel time	Various			-1.29 -1.16 -0.90 -0.59 -0.55	Estimates are for bus and rapid transit All trips (San Francisco) Work trips (San Francisco) Work trips (Chicago) Shopping trips (Boston) All trips (San Francisco)	McGillivary (1969), Lave (1969), and Domencich et al. (1968), cited in Lago et al. (1981b)	←
Various	Travel time	Literature review			-1.03 -0.92	SD: +/- 0.13 (2 cases) SD: +/- 0.37 (2 cases)	Lago et al. (1980), cited in Multi-Systems (1982)	←

Appendix F: Fuel Prices

F1. Direct Effects

F1.1 Introduction

This appendix (with Tables F1, F2) details the New Zealand and international evidence on the direct effects of changes in fuel prices with respect to the following:

- Car travel demand (i.e. the transport demand direct elasticity); and
- Public transport travel demand, as expressed through:
  - the cross-elasticity of public transport demand with changes in fuel prices, and/or
  - the proportion of people deterred from car use who, because of fuel price increases, switch to public transport (the 'diversion rate').

Demand is generally measured in terms of the number of vehicle or person trips, although some studies have also examined the impact on demand in terms of vehicle kilometres travelled.

A substantial body of international literature is available on the effects of changes in total fuel consumption as a result of fuel price changes (primarily increases). A considerable number of studies have been undertaken since the first oil shock in 1973, but this evidence is not summarised in this report.

By comparison, the effect of fuel price changes on traffic levels has been researched to a lesser extent. The elasticity of car travel demand with respect to petrol price might be expected to be less than the elasticity of petrol consumption. Behavioural adaptations are possible even in the short run, such as changes in driving styles and speed, use of smaller cars in multi-car households, etc. In the longer run, the evidence is that the car travel elasticity would be substantially lower than fuel consumption elasticity as a result of changes in vehicle size, energy efficiency, etc.

F1.2 International Evidence

F1.2.1 Overall Estimates

The direct car travel demand elasticities derived from international evidence are set out in Table F1, and the following section summarises the key findings.

One of the most comprehensive reviews was that completed by Goodwin (1992) who examined some 16 countries and grouped estimates into SR, LR, and those where the time period was unclear or ambiguous. Goodwin also separated the results into study types (i.e. cross-sectional and time series analysis). Mean outcomes for all markets, all day, included:

- Time series analysis:
  –0.16 SR (4 studies)
  –0.33 LR (4 studies)
  –0.46 undefined (5 studies)
- Cross-sectional analysis:
  –0.29 long run (2 studies)
  –0.50 undefined (1 study)

A more recent major review of European studies (de Jong & Gunn 2001) found an SR average of –0.16 (in terms of vehicle trips and vehicle kms) and LR averages of -0.19 (vehicle trips) and –0.26 (vehicle kilometres).

The results of these two major reviews are generally supported by a range of other recent US and European studies, including Algers et al. (1995), Schimek (1997), Storchmann (2001), and Johansson & Schipper (1997).

Most, but by no means all, of the literature indicates that LR values are somewhat greater than SR values: typically LR estimates are around 50% greater than SR estimates. A priori, there are grounds for expecting higher estimates in the LR as people may move house, change jobs, etc., but also grounds for expecting lower estimates related to using more fuel-efficient cars, etc.

F1.2.2 Disaggregate Estimates

A limited number of studies segmented the market according to time of day, travel purpose or socio-economic variables. Often the available data was insufficient to formulate significant conclusions. The major findings included:

- **Trip purpose.** de Jong & Gunn (2001) undertook comprehensive analyses by trip purpose. With the exception of home-based and non-home based business travel which were found to be relatively inelastic (i.e. values as low as –0.02 for the SR), no clear pattern between the other market segments emerged. Similarly, Algers et al. (1995) in their mode choice modelling found only marginal differences between work trip travel demand and total travel demand (i.e. –0.16 and –0.14 respectively).
- **Time of day.** Lewis (1977) estimated SR values for London travellers of –0.04 for morning peak travel, –0.09 for all weekday travel, –0.35 for Saturday travel, and –0.36 for Sunday travel.

F1.3 Australian and New Zealand Evidence

F1.3.1 Overall Estimates

Table F2 provides details of the Australian evidence on private vehicle demand with respect to changes in fuel prices. We have not been able to identify any New Zealand evidence on this topic.

Much of the Australian research has been undertaken by Hensher, primarily in studies carried out during the 1980s. Overall travel demand elasticities were estimated at about –0.10 in the SR and about –0.26 in the LR (different model forms give differing results).

An earlier study by Filmer & Mannion (1979) found substantially lower values (-0.03 SR, –0.07 LR), but with similar relativities between SR and LR results.

F1.3.2 Disaggregated Estimates

Limited evidence exists on disaggregate estimates by time of day, trip purpose or other forms of segmentation. One study by Lane (cited in WCS 1991) found that car use elasticity for work trips was –0.10 compared to –0.20 for recreational trips, although it is unclear whether these values relate to petrol consumption.

Hensher's work disaggregated elasticities according to household car ownership. In the short run, it appeared that single car households had the highest elasticities (perhaps surprisingly); while in the long run multiple car households had higher elasticities. Little international evidence is available to corroborate these results.

F1.4 Conclusions

Only limited direct New Zealand evidence relates to the effects of fuel price changes on car travel demand. Therefore the international evidence needs to be used to draw conclusions for the New Zealand situation. This evidence does not indicate substantially different elasticity values between countries and can therefore be made use of, with caution, in deriving values applicable to the New Zealand situation.

We suggest that most weight should be placed on the average elasticity values found in a number of international reviews, particularly those by Goodwin (1992) and Luk & Hepburn (1993). In determining the most appropriate values for the New Zealand market, particular attention should be paid to the Australian evidence. We would expect New Zealand estimates to be of broadly similar magnitude to those in Australia, and perhaps lower than those typical in Europe. Relative to Europe, New Zealand has lower petrol prices and limited alternative modes.

On this basis, we suggest the following range of values suitable to the New Zealand urban centres:

• SR (within 12 months):	central estimate –0.15
	typical range –0.10 to –0.20
• LR (5 years or more):	central estimate –0.25
	typical range –0.20 to –0.30

Very limited evidence is available on disaggregation of values by market segment. However, as expected, the available evidence indicates that non-discretionary travel is less price-sensitive than discretionary travel (i.e. elasticities for work trips are typically around half the values for other trip purposes); and weekend elasticities are substantially higher than weekday elasticities.

While limited explicit evidence is available, elasticity responses are assumed to be symmetric to increases and to decreases in petrol prices.

F2. Cross-Modal Effects

F2.1 Introduction

This section examines the effects of increases in petrol prices on public transport usage in two complementary ways:

- Through cross-elasticity measures; and
- Through the proportion of 'deterred' car travellers who switch to public transport.

The latter approach is regarded as generally more useful, although the evidence is limited.

F2.2 International Evidence

F2.2.1 Overall Estimates

While extensive evidence is available on direct fuel price elasticities of demand with respect to private vehicle transport, international information available on cross-elasticities is relatively limited (Table F3). Also there appears to be wide variation in the cross-elasticity estimates both within and between studies. Key factors contributing to this observed variation may include:

- The presence and strength of intermodal competition (initial mode shares);
- Model specification (i.e. different functional forms); and
- Differences in time horizons (i.e. SR compared to LR).

As such, care should be exercised when interpreting the results.

Goodwin (1992) identified five results from three studies and found an average cross-elasticity of 0.34, however values ranged from 0.08 to 0.80. A number of studies have observed short-run estimates towards the lower end of this range (i.e. around 0.10 or lower) including Storchmann (2001), Boulahbal & Madre (2000), Algers et al. (1995), and Rose (1986). De Jong & Gunn (2001) estimated a relatively high overall SR value of 0.33 in terms of numbers of public transport trips, but a much lower value of 0.07 in terms of public transport person kilometres.

Direct evidence on the share of 'deterred' car travellers that switch to public transport is even more limited. In UK and European metropolitan areas, the proportion of deterred motorists who would switch to public transport generally ranged from 25% to 50%. Brog (1984) used a stated response survey to estimate the diversion shares in Germany. He found that 20% to 30% of deterred car users would switch to public transport, depending on the level of the petrol price increase.

The weight of available evidence suggests LR cross-elasticity values are generally 50% to 100% higher than SR values. This however is not always the case. In the longer run people will possibly pursue other adaptive mechanisms (e.g. move house or job) rather than continue to use public transport.

F2.2.2 Disaggregate Estimates

Very few studies provided disaggregate cross-elasticity or diversion rate estimates:

- **Trip purpose.** Algers et al. (1995) and de Jong & Gunn (2001) segmented the market according to trip purpose and found somewhat higher cross-elasticities for the commuter market relative to other markets. Several UK studies indicated that the peak period diversion rates to public transport would typically be 50% or greater; whereas the off-peak diversion rates would be much lower, in the order of 25%.
- **Trip distance.** Based on stated response surveys, Heggie (1976) estimated that 32% of deterred car travellers would divert to public transport for short trips, compared to as much as 73% for longer trips.

F2.3 Australian and New Zealand Evidence

F2.3.1 Overall Estimates

Few Australian and New Zealand studies have examined the cross-elasticity of public transport demand with respect to changes in fuel prices. The available studies show a considerable range in cross-elasticity estimates (Table F4).

A recent study by Booz Allen Hamilton (2001a) of changes in petrol prices over the 1998 to 2000 period estimated an overall SR price cross-elasticity of 0.18 for Wellington City and 0.16 for the Hutt Valley. These values compare to an earlier New Zealand study which derived a much lower cross-elasticity of 0.07, although this result was not significantly different from zero (Travers Morgan 1990a).

The Australian studies give a wider range of cross-elasticity results, with SR estimates ranging from 0.07 to 0.70.

No Australian and New Zealand studies have directly examined diversion rates to public transport, however the following related information was found:

- Holsman & Lonergan (1980) in their Sydney Household survey found that the impact of rising fuel prices in Sydney resulted in 1% of respondents making greater use of public transport.
- Johnston et al. (1983) examined the before and after effects of carless days in Christchurch during 1979/80 on car drivers, which showed a 3% shift to buses.

These relatively low 'switching' effects are consistent with a general pattern in cities with lower density and poorer public transport services, such as North America, Australia and New Zealand, compared to higher density cities throughout Europe and the UK.

F2.3.2 Disaggregate Estimates

Even fewer studies in Australia or New Zealand have derived disaggregate cross-elasticity estimates.

Most relevant is the recent study in Wellington City (Booz Allen Hamilton 2001a), which estimated separate peak and off-peak elasticities. It found a peak cross-elasticity of 0.29 and an off-peak value of 0.11. These relative values are consistent with the more discretionary nature of off-peak trips, the poorer levels of public transport service to cater for such trips, and the lower mode share held by public transport in off-peak periods.

F2.4 Conclusions

As discussed in Chapter 2 of this report, cross-elasticity values are very much influenced by relative private and public transport 'base' mode shares, and are therefore less readily transferable between cities/countries and situations than are direct elasticity values. For these reasons, our preferred approach is to focus on 'diversion rates', i.e. the proportion of people deterred from car use who would switch to public transport. Such rates are considered to be much more transferable between different situations.

Unfortunately, most relevant studies have estimated cross-elasticities and very few have derived diversion rates directly. While diversion rates may be derived from cross-elasticities data and mode shares, the required mode share data are generally not readily available. Therefore our conclusions address both diversion rates and cross-elasticity estimates.

In terms of **diversion rates** in response to fuel price changes, our conclusions are that:

- Around 30% of person trips deterred from car use by higher fuel prices would switch to public transport in New Zealand urban centres.
- For peak/work travel, this proportion is likely to be around 40-50%, for off-peak/non-work travel around 15-20%.
- These diversion rate proportions will tend to be higher in situations where public transport service levels are relatively high (e.g. into CBD), lower where they are relatively poor (e.g. cross-suburban trips).

These proportions will tend to be higher than average for longer trips, lower for shorter trips (where walking or cycling are competitive alternatives).

In terms of **cross-elasticity** values (if required), the values obtained from the Wellington study provide the best guide, i.e. an overall SR cross-elasticity in the range 0.15 to 0.20, with peak cross-elasticity (around 0.30) being two to three times as high as the off-peak cross-elasticity (around 0.10). We would expect the LR value to be somewhat (in the order of 50%) higher than the SR value.

Table F1: Fuel Price Direct Elasticities – International Evidence

City/Country	Study Type and Period	Elasticity			Market Segment	Comments	Source	Rank
		Short Run	Long Run	Not Stated				
Various	Literature review Time Series studies (1978-86)	-0.16	-0.33	-0.46		SR: SD 0.08, 4 cases LR: SD 0.11, 4 cases NS: SD 0.40, 5 cases	Goodwin (1992)	←←←
Various	Literature review of cross-sectional studies (1976-86)		-0.29	-0.50		LR: SD 0.06, 2 cases NS: 1 case	Goodwin (1992)	←←←
Various	Literature review	-0.10 to -0.30				Demand is measured in terms of VKT or trips.	Fowkes et al. (1992). cited in Halcrow Fox (1993a)	
Europe	Literature review	-0.16	-0.19		All User Groups	Summary results (mean unweighted) of various European studies undertaken (generally) from 1985 onwards. Car travel demand is measured in terms of trips. Author notes that the ranges of values between studies is varied.	de Jong & Gunn (2001)	←←←
		-0.20	-0.14		Commuting Trips			
		-0.06	-0.07		Home-Based (HB) Business			
		-0.06	-0.17		Non HB Business			
		-0.22	-0.40		Education			
		-0.20	-0.15		Other			
Europe	Literature review	-0.16	-0.26		All User Groups	Summary results (mean unweighted) of various European studies undertaken (generally) from 1985 onwards. Car travel demand is measured in terms of vehicle kilometers travelled (VKT). Author notes that the ranges of values between studies is varied.	de Jong & Gunn (2001)	←←←
		-0.12	-0.23		Commuting Trips			
		-0.02	-0.20		Home-Based (HB) Business			
		-0.02	-0.26		Non HB Business			
		-0.09	-0.41		Education			
		-0.20	-0.29		Other			
Various	Review of the literature	-0.23	-0.06	-0.26 to -0.29	1 Car Households	Values obtained by a literature review of studies that examined car usage and fuel consumption.	Halcrow Fox (1995)	←
		-0.28	-0.10	-0.13 to -0.34	2 Car Households			
Hong Kong	Time Series (1976-93)	-0.25			Log model form	SE: 0.073	Walls (1998)	←←
		-0.20			Trend model form	SE: 0.040		
		-0.19			First difference model form	SE: 0.052 Car travel demand is measured in terms of VKT.		

Table F1: Fuel Price Direct Elasticities – International Evidence

City/Country	Study Type and Period	Elasticity			Market Segment	Comments	Source	Rank
		Short Run	Long Run	Not Stated				
London	Time Series (1972-77)	-0.04 -0.09 -0.35 -0.36 -0.08			AM Peak Weekday (24hr) Saturday Sunday Weekly	95% CI: +/- 0.03 95% CI: +/- 0.04 95% CI: +/- 0.19 95% CI: +/- 0.21 95% CI: +/- 0.03 Author notes that the peak and weekend CIs do not overlap, indicating they are statistically different from one another. Car travel demand is measured in terms of journeys.	Lewis (1977)	←
UK	Time Series (1972-78)	-0.11 -0.13 -0.17			Regression Model 1 Regression Model 2 Box Jenkins Model	SE: +/- 0.05 SE: +/- 0.04 SE: +/- 0.07 Demand is measured in terms of car kms. Author found no significant difference between increasing and decreasing petrol elasticities.	Oldfield (1980)	←
USA	Time Series (1950-94)		-0.26			Lagged time series model (medium to long run interpretation). Involved adjustment period of 4.4 years (SR value -0.06). Elasticity relates to annual distance travelled per vehicle (vehicles/capita elasticity additional, at -0.16). Result was statistically significant.	Schimek (1997)	←←
Various	Pooled cross-sectional and Time Series models (1973-92)		-0.05 to -0.55 -0.30		Range Authors' best guess	Data from 12 OECD countries including Australia. Tested different functional forms and estimation techniques.	Johansson & Schipper (1997)	←←
Germany	Econometric modelling (1950-94)	-0.10				Author noted that estimates are much higher for leisure and holiday travel.	Storchmann (2001)	←
Europe	Time Series (1965-80)	-0.29 -0.34			Kms per car Fuel per car	SE: +/- 0.08 SE: +/- 0.12 Based on average annual data from 12 European nations.	Tanner (1983), cited in Bland (1984)	
Europe			-0.30 to -0.50			Demand is measured in terms of VKT.	OECD, cited in Balcombe et al. (2004)	

Table F1: Fuel Price Direct Elasticities – International Evidence

City/Country	Study Type and Period	Elasticity			Market Segment	Comments	Source	Rank
		Short Run	Long Run	Not Stated				
Puget Sound (USA)						Noted that a $0.40 to $2.00 fuel increase would lead to a 1.2% to 6.7% decrease in vehicle trips and a 1.4% to 7.2% decrease in vehicle kilometers travelled.	PSRC, cited in VTPI (2002)	
Sweden	Transport modelling (1986/87)			-0.14 -0.16	All Trips Work Trips	Author also measured demand in terms of VKT and found work trip and all trip elasticites of -0.31 and -0.33 respectively.	Algers et al. (1995)	←
USA	Mode choice modelling (1980)	-0.15 to -0.20				Examined various urban areas in the US (Milwaukee, Madison, Fox River Valley and other cities). Elasticities provided are point estimates.	Kocur et al. (1982)	←
Israel	Time series (1965-77)	-0.18 -0.20	-0.25 -0.34		Monthly Data Quarterly Data	SR SE: +/- 0.031, LR SE: +/- 0.036 SR SE: +/- 0.040, LR SE: +/- 0.056 Estimates related to fuel usage per car.	Straus & Ben Yehoshua (1980), cited in Bland (1984)	←←
Belgium	Time series (1961-80)	-0.22	-0.27	-0.33		Annual data Values provided were calculated from Vaes' elasticities of car fuel minus the elasticity of car ownership.	Vaes (1982), cited in Bland (1984)	←
Various	Literature review (Time series)	-0.20	-0.30				Bland (1984)	←←
Various	Literature review	-0.10					National Transport Planning Framework - Urban Transport Working Group (1995)	←
Various	Literature review	-0.10 to -0.20	-0.25 to -0.50				INFRAS (2000)	←←

Table F2: Fuel Price Direct Elasticities – Australian and New Zealand Evidence

City/Country	Study Type and Period	Elasticity			Market Segment	Comments	Source	Rank
		Short Run	Long Run	Not Stated				
Sydney	Regression analyses on household panel data, Sydney area, 1981-85.	-0.10 -0.45* -0.35 -0.30	-0.26 -0.22/-0.28 -0.30/-0.34 -0.52/-0.39		Overall 1 car per household 2 cars per household 3 cars per household	This review focused on studies undertaken by Hensher and colleagues during the 1980s. SR and first LR elasticities relate to first wave of a 4-wave panel; second LR elasticities relate to all 4 waves of panel data. * Represents an inconsistent result. Authors note that the sensitivity of car use to rising fuel prices would be reduced by rising real incomes, the existence of business registered vehicles, increasing suburban/fringe development and the strong need for car travel in those areas.	Hensher (1985), Hensher et al. (1990), cited in Luk & Hepburn (1993)	←←
Sydney	Time series analysis (1961-88)			-0.17 -0.21	OLS 2SLS	Authors test a number of regression model formulations.	Hensher & Young (1991), cited in Balcombe et al. (2004)	←←
Sydney	Cross-sectional analysis (1981-82)	-0.24 -0.09 -0.10	-0.31 -0.22 -0.26		OLS 2SLS 3SLS	Authors test a number of regression model formulations – all the reported estimates were statistically significant.	Hensher & Smith (1986)	←←
Australia				-0.10 -0.20	Work Trips Recreational Trips	Values possibly relate to petrol consumption.	Lane (1977), cited in WCS (1991)	• ←
Australia	Literature review	-0.10	-0.26			No original sources.	Bray & Ass (1995)	←
Sydney						Survey results of 224 Sydney households found that 24% of respondents made less use of the car following a petrol price increase, although the magnitude of the change in price was undefined.	Holsman & Lonergan (1980)	
Australia		-0.03	-0.07			Authors also found that urban and non-urban travel would be reduced by the same extent.	Filmer & Mannion (1979), cited in Travers Morgan (1980a)	←
Australia		-0.09 to -0.24	-0.22 to -0.31	-0.22 to -0.53 -0.25 to -0.34		Summary of various studies.	Oum et al. (1992), cited in Travers Morgan (1995)	

Table F3: Fuel Price Cross-Modal Elasticities – International Evidence

City/Country	Study Type and Period	Elasticity			Market Segment	Comments	Source	Rank
		Short Run	Long Run	Not Stated				
UK	Literature review			0.34		Average estimate obtained from 5 studies which ranged from 0.08 to 0.80.	Goodwin (1992)	←←
Europe	Literature review	0.33	0.07		Overall	Summary results (mean unweighted) of various European studies undertaken (generally) from 1985 onwards. Public transport travel demand is measured in terms of trips. Author notes that the range of values between studies is varied.	de Jong & Gunn (2001)	• ←
			0.12		Commuter			
		0.17	0.03		HB Business			←
		0.17			NHB Business			
			0.14		Education			←
		0.48	0.07		Other			
Europe	Literature review	0.07	0.10		Overall	Summary results (mean unweighted) of various European studies undertaken (generally) from 1985 onwards. Public transport travel demand is measured in terms of VKT. Author notes that the range of values between studies is varied.	De Jong & Gunn (2001)	←
			0.26		Commuter			
Chicago	Time Series (1970-81)	0.11	0.18				Rose (1986)	←
France	Time Series (1975-95)	0.10	0.19				Boulahbal & Madre (2000)	←
London						Estimated the proportion of the reduction in car passengers that divert to public transport was around 4.7%. Urge caution with this estimate since model does not isolate urban and inter-urban trips.	Acutt & Dodgson (1996)	
Germany	Econometric Modelling (1980-98)	0.07					Storchmann (2001)	←
USA				0.62		Bus use. Based on analysis in 6 US cities.	Dodgson (1990), cited in Halcrow Fox (1993a)	←

Table F3: Fuel Price Cross-Modal Elasticities – International Evidence

City/Country	Study Type and Period	Elasticity			Market Segment	Comments	Source	Rank
		Short Run	Long Run	Not Stated				
UK	Stated response					Reported on trips affected by petrol rationing in a small provincial town: for short trips (<4 miles) 32% of deterred travellers use public transport; for longer trips (>4miles) 73% of deterred travellers use public transport.	Heggie (1976)	←
London	Stated response					Reported on trips affected by petrol rationing in London: for peak trips, 50% of deterred travellers use public transport; for off peak trips, 25% of deterred travellers use public transport.	Collins & Fowler (1975), cited in Heggie (1976)	←
London	Stated response					Analysis of reported behaviour of motorists affected by petrol rationing in London: found overall, transfer to public transport will not be much more than half the level of suppression; and for peak period more trips will transfer to public transport than will be suppressed.	London Transport Study, cited in Heggie (1976)	←
Sweden	Transport model			0.06 0.09	All Trips Work Trips	Authors also measured demand in terms of VKT and found work trip and all trip elasticities of 0.13 and 0.09 respectively.	Algers et al. (1995)	←
USA				0.08 to 0.80			Wang & Skinner (1984)	
USA	Mode choice modelling (1980)	0.25 to 0.45				Examined various urban areas in the US (Milwaukee, Madison, Fox River Valley and other cities). Elasticities provided are point estimates.	Kocur et al. (1982)	←
Various	Literature review	0.07					National Transport Planning Framework - Urban Transport Working Group (1995)	
Netherlands		0.14 0.26			Public Transport Rail		Bovy et al. (1991)	←

Table F3: Fuel Price Cross-Modal Elasticities – International Evidence

City/Country	Study Type and Period	Elasticity			Market Segment	Comments	Source	Rank
		Short Run	Long Run	Not Stated				
Germany	Stated response					Estimated the proportion of 'deterred' car users that would use public transport are as follows: 25% (50% increase in petrol prices), 20% (100% increase in petrol prices), 30% (150% increase in petrol prices).	Broeg (1984)	←

Table F4: Fuel Price Cross-Modal Elasticities – Australian and New Zealand Evidence

City/Country	Study Type and Period	Elasticity			Market Segment	Comments	Source	Rank
		Short Run	Long Run	Not Stated				
Wellington City	Time Series (1998-00)	0.18 0.11 0.29			All Day Off-Peak Peak	95% CI: +/- 0.13 to 0.24 (all day) 95% CI: +/- 0.05 to 0.17 (off-peak) 95% CI: +/- 0.21 to 0.37 (peak)	Booz Allen Hamilton (2001a)	←←←
Hutt Valley		0.16			All Day	95% CI: +/- 0.00 to 0.32 (all day) Weekly data series Results were statistically significant.		
Adelaide	Time Series (1985-93)			0.44 0.35	Linear model form Log model form	Results were statistically significant	Willis (1994)	• ← ←
Sydney	Joint RP and SP	0.17			Peak commuter		Taplin et al. (1999)	←←
Melbourne	Time Series (1978/79 – 1995/96)			0.70		Statistically significant rail estimate	Booz Allen Hamilton (1999a)	←
Sydney	Stated response					Survey results of 224 Sydney households found that 1% of respondents made greater use of public transport following a petrol price increase, although the magnitude of the change in price was undefined.	Holsman & Lonergan (1980)	
New Zealand	Time Series (1974/75-1988/89)	0.07					Travers Morgan (1990a)	←
Australia	Literature review	0.07					Bray & Ass. (1995)	←
Christchurch	Stated response					Surveys examining the effects of carless days in Christchurch – found 3% of deterred car drivers used public transport	Johnston et al. (1983)	

Appendix G: Vehicle Operating Costs

G1. Direct Effects

G1.1 Introduction

This Appendix G examines the evidence on the direct effects of changes in overall vehicle (car) operating costs on:

- Car travel demand (i.e. the direct elasticity effect); and
- Public transport travel demand, as measured through either cross-elasticities or 'diversion rates'.

Operating costs are assumed to include both fixed costs and variable costs. Variable costs include for example fuel costs and distance-related maintenance costs (e.g. tyres, oil, etc.). Fixed costs generally include road taxes, insurance and most depreciation. Often however, the literature is unclear with regard to the definition of 'vehicle operating costs' and frequently fuel costs are used as a proxy measure.

Studies that only considered fuel costs have been covered in Appendix F. Studies which cover the wider definition of vehicle operating costs are considered in this Appendix G, although the precise costs covered are often not well-defined and are likely to differ between different studies.

G1.2 International Evidence

G1.2.1 Overall Estimates

As detailed in Table G1, the international literature was relatively limited. One of the most comprehensive reviews in this area was undertaken by Oum et al. (1992). This review examined seven single mode studies in three countries (US, Australia and the UK). All these studies use household survey data, except one that was based on observations of demand changes before and after a price change. The measure of 'vehicle operating costs' in each case was unclear. Elasticity estimates (based on vehicle kilometres) ranged from –0.09 to –0.24 (SR), –0.22 to –0.31 (LR) and –0.13 to –0.52 for an undefined period. Oum et al. noted that, although the LR estimates are in general higher, the differences were limited. The review concluded that this might be because few studies develop true LR models which take into account changes in vehicle ownership and location choice. It also concluded that the estimates for the three different countries were remarkably similar.

A limited number of other studies were found in the US. McFadden (1974) estimated a value as high as –0.47 for San Francisco, and Chu (2001) observed values ranging from –0.18 to –0.28 in Chicago using logit model formulations.

In Europe also, there are only a few relevant studies. In Olso, Ramjerdi (1994) observed relatively elastic estimates that ranged from –0.7 to –0.8. These values are significantly higher than the Oum et al. (1996) estimates for 'out-of-pocket' expenses of –0.02 (SR) and –0.28 (LR) for the Netherlands.

G1.2.2 Disaggregate Estimates

Even fewer studies segmented the market according to trip purpose, time of day or other variables:

Time of day/trip purpose. Kirwan et al. (1997, cited in O'Mahony et al. 1997) found that values varied by time of day in Dublin (–0.40 in the peak and –0.65 in the off-peak). Similarly, de Borger et al. (1996) found estimates ranged between peak and off-peak periods in Belgium (i.e. –0.38 peak and –0.53 off-peak), although the time horizon was undefined. Mackett, cited in Banister et al. (date unknown), used a land use/transport modelling approach to examine the sensitivity of work trip demand with respect to changes in vehicle operating costs for three cities, Tokyo (–0.06), Leeds (–0.29) and Dortmund (–0.23).

G1.3 Australian and New Zealand Evidence

The Australian evidence was different between studies, although the tendency was for estimates to be highly inelastic. Our review did not find any New Zealand evidence of car travel demand with respect to vehicle operating costs. Table G2 details the findings of our review and the main points are summarised below.

G1.3.1 Overall Estimates

Three of the seven studies reviewed by Oum et al. (1992) related to Australian evidence. These gave estimates in the range of –0.09 to –0.24 (SR), –0.22 to –0.31 (LR) and –0.22 to –0.52 (period undefined). These findings compare to much lower estimates found by Hensher (1986, cited in IC 1994) for Sydney. He estimated a direct elasticity of –0.08 for car drivers and –0.02 for car passengers. It is unclear whether these values were SR and LR estimates.

G1.3.2 Disaggregate Estimates

Most disaggregated elasticity studies focussed on peak work travel estimates, although the findings varied between studies:

Time of day. Madan & Groenhout (1987), which continued from the earlier analysis of peak work travel, estimated a SR value of –0.04; and

Trip type. By comparison, Shepherd (1972) undertook a cross-sectional analysis of demand for peak CBD trips with respect to car operating costs in 1964 and observed a value as high as –0.34, although the time horizon was undefined.

G1.4 Conclusions

Given the lack of direct New Zealand evidence on this topic, the international situation needs to be used in drawing conclusions for New Zealand. The relatively similar findings of Oum et al. (1992) from studies in the US, UK and Australia suggest that international evidence should be reasonably transferable.

We suggest that most weight should be placed on the average elasticity values found in a number of major reviews, particularly Australian evidence from Oum et al.

(1992). New Zealand estimates would be expected to be of a broadly similar magnitude to those in Australia.

On this basis, the evidence would suggest the following values might apply for New Zealand urban centres:

SR: average –0.20 (typical range –0.10 to –0.25);
LR: average –0.30 (typical range –0.20 to –0.40).

Worth noting is that these values are slightly higher than those recommended in Appendix F for petrol prices, i.e. –0.15 average for SR, –0.25 average for LR. The elasticities for total vehicle operating costs might have been expected to have been at least twice as great, or more, than the fuel cost elasticities, as total operating costs are well over twice fuel costs in most situations. The relatively small difference in the elasticities suggests that the vehicle operating cost estimates may often not include all operating cost components (particularly fixed cost components), and in some cases may represent fuel costs only.

Given this uncertainly and inconsistency, we recommend giving little weight to the evidence on 'vehicle operating cost' elasticities; and in preference suggest constructing such elasticity values based on the fuel price elasticities and information on the relative levels of other operating cost components (where required).

Thus no attempt has been made to draw any separate conclusions on the disaggregation of vehicle operating cost elasticity values.

G2. Cross-Modal Effects

G2.1 International Evidence

G2.1.1 Overall Estimates

Table G3 summarises the very limited international evidence available on the sensitivity of public transport demand to changes in vehicle operating costs. Major findings included (in most cases it is unclear whether values relate to SR or LR):

- Wardman (1997) estimated cross-elasticities for rail and bus of 0.84 and 0.48 respectively. These results were derived from his own estimates using relative market shares (i.e. 14% bus and 2% rail) and assumed diversion factors (40% car to bus and 10% car to rail).

- Toner (cited in Wardman 1997) derived lower values for rail (0.34) than for bus (0.62). However, Wardman cautioned against the accuracy of these results.

- McFadden (1974) observed values around 0.80 for both bus and rail in San Francisco.

However, most other international studies have estimated lower values, with Bovy et al. (1991) deriving an estimate of 0.22 (SR), and some other studies estimating values lower than 0.10. Consistent with this, TRRL (1980) concluded that rising fuel prices lead to car owners making shorter trips, but not generally switching to public transport, except in large conurbations where public transport might be expected to be more competitive with private cars.

G2.1.2 Disaggregate Estimates

A few studies generated disaggregated elasticity estimates including:

Time of day/trip purpose. de Borger et al. (1996) observed higher cross-elasticity estimates for peak (0.04) than off-peak (0.02), although both figures are very low. Bovy et al. (1991) also estimated higher SR values for commuter trips (0.39) than for all trips (0.22).

G2.2 Australian and New Zealand Evidence

G2.2.1 Overall Estimates

A couple of New Zealand and Australian studies have examined the effect on public transport demand of changes in vehicle operating costs (refer Table G4).

For Australia, Hensher (cited in Industry Commission 1994) observed differences between modes. Results suggested that cross-elasticities were higher for rail compared to bus (i.e. 0.11 and 0.04 respectively). This result is consistent with the common view that rail is more competitive than bus as an alternative to car use (although it is also influenced by the base mode shares).

Some of the key findings from New Zealand include:

- Pringle (1979) analysed time series data for the period 1967 to 1978 in New Zealand. This study noted that the use of urban public transport was virtually unaffected by the dramatic increases in motoring costs (or fuel costs) which occurred during the 1970s. Public transport use was found to have an elasticity of 0.09 with respect total car operating costs. (This is similar to the fuel price cross-elasticity for New Zealand urban centres of 0.07 estimated by Travers Morgan 1990a, Table F4.)

- A New Zealand study by Galt & Eyre (1987) analysed data for Greyhound buses (in Wanganui) over the period 1978 to 1985, including the period of carless days (1979/80). They estimated that carless days resulted in a 6% rise in bus patronage while the programme was in force, although the equivalent cross-elasticity is not known. Galt & Eyre also cite that a number of studies had estimated elasticities of demand for bus travel with respect to car operating costs between the 0.2 and 1.4.

G2.2.2 Disaggregate Estimates

No disaggregate estimates were found for Australia and New Zealand aside from a 1964 cross-sectional analysis by Shepherd (1972), which found values as low as 0.08 for peak CBD work trips in Melbourne.

G2.3 Conclusions

As discussed in Appendix F, our preferred approach to estimating cross-modal effects is through diversion rates rather than cross-elasticity estimates.

In any event, as discussed in Section G1, the most appropriate approach considered is to estimate cross-modal effects first for fuel prices, and then adjust the results as appropriate for total vehicle operating costs. In this case, we see no reason why the diversion rate estimates for fuel prices (Section F2.4) should not also apply to vehicle operating costs.

Table G1: Vehicle Operating Cost Direct Elasticities – International Evidence

City/Country	Study Type and Period	Elasticity			Market Segment	Comments	Source	Rank
		Short Run	Long Run	Not Stated				
USA	Literature Review	-0.23	-0.28	-0.13 to -0.26 -0.15 to -0.45		Results were from several single mode studies. Car demand is measured in terms of VKT.	Oum et al. (1992)	←←
UK	Literature Review			-0.14 to -0.36		Results were from several single mode studies. Car demand is measured in terms of VKT.	Oum et al. (1992)	←←
Netherlands		-0.02	-0.28			Vehicle operating costs are defined as "out-of-pocket" expenses.	Oum et al. (1996)	←
Dortmund	Transport Model			-0.23	Work trips		Mackett (1990), cited in Banister et al. (nd)	←
Leeds	Transport Model			-0.29	Work trips		Mackett (1990), cited in Banister et al. (nd)	←
Tokyo	Transport Model			-0.06	Work trips		Mackett (1990), cited in Banister et al. (nd)	←
USA				-0.47			McFadden (1974)	
Belgium	Transportation Model			-0.38 -0.53	Peak Off-Peak		De Borger et al. (1996)	←←
	Time Series (1956 to 1984)	-0.22					Mayo & Mathis (1988), cited in Greene (1992)	
Oslo				-0.70 to -0.80		Values are implied direct elasticities.	Ramjerdi (1994)	←←
Chicago	Mode Choice Modelling			-0.18 to -0.28	CBD Trips		Chu (2001)	←←
Boston	Cross-sectional Analysis			-0.49 -0.88	Work trips Shopping trips	VOC is defined as car in-vehicle money cost.	Charles River Ass., cited in Kemp (1974); Kemp (1973)	←←
				-2.0 to -3.2 -0.30 to -2.9 -0.7 to -2.9 -0.6 to -2.1	Shopping Urban Commuting Inter-urban Business Inter-urban Leisure		Button (1993), cited in VTPI (2002)	←
Dublin				-0.40 -0.65	Peak Off-Peak		Kirwan et al. (1997), cited in O'Mahony et al. (1997)	←

Table G2: Vehicle Operating Cost Direct Elasticities – Australian and New Zealand Evidence

City/Country	Study Type and Period	Elasticity			Market Segment	Comments	Source	Rank
		Short Run	Long Run	Not Stated				
Sydney	Mode Choice Modelling			-0.04		Unclear whether this estimate refers to petrol prices or total vehicle operating costs. The author notes that the elasticity is a probability weighted average of individual elasticities and that point elasticities are typically higher.	Madan & Groenhout (1987)	←
Sydney	RP and SP joint model (1996/97)			-0.09	Commuter trips		Taplin et al. (1999)	
Sydney	Mode Choice Modelling			-0.08 -0.02	Car Driver Car Passenger		Hensher (1986), cited in Industry Commission (1994)	←
Australia	Literature Review	-0.09 to -0.24	-0.22 to -0.31	-0.22 to -0.52 -0.25 to -0.34		Results were from several single mode studies. Car demand is measured in terms of VKT.	Hensher (1985), Hensher & Smith (1986), Hensher et al. (1990), cited in Oum et al. (1992)	←←

Table G3: Vehicle Operating Cost Cross-Modal Elasticities – International Evidence

City/Country	Study Type and Period	Elasticity			Market Segment	Comments	Source	Rank
		Short Run	Long Run	Not Stated				
		0.22 0.39			All Markets Commuters		Bovy et al. (1991)	
Dortmund	Transport Model			0.40	Work trips		Mackett (1990), cited in Banister et al. (nd)	←
Leeds	Transport Model			0.31	Work trips		Mackett (1990), cited in Banister et al. (nd)	←
Tokyo	Transport Model			0.03	Work trips		Mackett (1990), cited in Banister et al. (nd)	←
Belgium	Transportation Model			0.04 0.02	Peak Off-Peak		de Borger et al. (1996)	←←
San Francisco US				0.81 0.82	Rail Bus		McFadden (1974)	
	Literature Review			0.34 0.62	Rail Bus	Review focused on mode choice models. Notably, Wardman comments on the inaccuracy of these results maintaining they don't account adequately for mode shares.	Toner, cited in Wardman (1997)	←
UK	Inferred Estimates			0.84 0.48	Rail Bus	Cross elasticities were derived from own elasticities on the basis of relative market shares and assumed diversion rates: Market share 84% car, 14% bus, 2% rail. Diversion: Car to bus 40%, Car to Rail 10%.	Wardman (1997)	←←
UK – England	Time Series regression models	0	0.33		All	Elasticity of bus trips wrt combined motoring cost index (running/purchase costs). Appears that SR estimate (<1 year) constrained to zero.	Dargay & Hanly (1999)	←

Table G4: Vehicle Operating Cost Cross-Modal Elasticities – Australian and New Zealand Evidence

City/Country	Study Type and Period	Elasticity			Market Segment	Comments	Source	Rank
		Short Run	Long Run	Not Stated				
Sydney	Mode Choice Modelling			0.11 0.04	Rail (Commuter) Bus (Commuter)		Hensher (1986), cited in IC (1994)	←
Sydney	Mode Choice Modelling			0.07		Unclear whether this estimate refers to petrol prices or total vehicle operating costs. The author notes that the elasticity is a probability weighted average of individual elasticities and that point elasticities are typically higher.	Madan & Groenhout (1987)	←
Melbourne	Cross-sectional (1964)			0.08	Peak CBD work trips		Shepherd (1972)	←
New Zealand						Analysis of the data revealed that the effect of changes in car operating costs resulted in a 6% rise in bus patronage.	Galt & Eyre (1987)	←
New Zealand	Time Series (1967 to 1978)			0.09			Pringle (1979)	←

Appendix H: Toll Charges

H1. Direct Effects

H1.1 Introduction

This Appendix H sets out the evidence available internationally on the direct effects of changes in road traffic tolls on:

- Car travel demand (i.e. the direct elasticity effect); and
- Public transport travel demand, as measured through either cross-elasticities or diversion rates.

The review considers the evidence under two types of tolling arrangements:

- Area-wide tolling schemes; and
- Tolling on individual routes (e.g. river crossings, routes with limited alternatives, etc.).

The traffic outcomes from each type of scheme are considered in turn, although area-wide tolling schemes are more relevant to this review as they impact on all traffic in an area. Individual route schemes on the other hand allow diversion of traffic to alternative routes (which is not usually recorded in studies), and hence their results are not readily transferable.

H1.2 International Evidence

H1.2.1 Area-wide Tolling Schemes

Actual international experience on the introduction of area-wide tolls is scarce (Table H1). Also often no clear distinction has been made between SR and LR results. Evidence of these types of schemes is available in three cities in Norway (Bergen, Olso and Trondheim), Milan and Singapore. Of these only Singapore set out to achieve a reduction in car use, and hence a shift towards public transport. In the three Norwegian cities, tolls for car drivers wishing to enter the central area were designed to provide additional funds for road construction (80%) and subsidies to public transport (20%), rather than to have a significant impact on mode split. Nevertheless, these situations enable the impacts of road user charges to be estimated.

Major findings relating to area-wide toll schemes are as follows:

- Halcrow Fox (1995) has shown that the elasticity of private vehicle use with respect to road charges typically ranges from –0.1 to –0.8. Halcrow Fox found that Oslo and Bergen recorded 5% and 6% to 7% reduction in traffic respectively. This translates to a toll elasticity for overall car traffic levels of –0.14 for Oslo and –0.21 for Bergen.

- Substantially lower estimates were derived by Ramjerdi (1994), in relation to a two-wave panel study that evaluated the impact of opening a toll ring in Oslo. The toll fee for crossing the cordon line around the city centre was 10 NOK (Norwegian krone). The toll elasticity of the number of car trips (tours) ranged from –0.03 to –0.04 (depending on model form). These elasticities might be regarded as low. However the author found that the cost of petrol was 7 NOK/litre and the cost of parking in central Oslo was about 31 NOK/day. Thus the toll was only a very small part of the generalised cost: and the implied marginal car cost elasticity of demand (for car drivers) was about –0.7 to –0.8 (i.e. similar to the values expected).
- Luk (1999) estimated a higher average value for Singapore of –0.34. Luk notes that the Singapore experience may be unique because, although car ownership is restricted to higher income residents who tend be price inelastic, this is offset by the excellent public transport service which makes car use more price-sensitive than in other cities.
- These results were not dissimilar to values obtained by Polak et al. (1994, cited in Halcrow Fox 1995) in their household survey in Singapore. Values as high as –1.5 for the initial toll increase and –0.4 for subsequent toll increases were observed.
- Hirschman et al. (1995) examined the impacts on traffic levels from automobile tolls on New York bridges and tunnels using a time series analysis of monthly vehicle crossings between 1979 and 1990. Observed values ranged from –0.03 to –0.50, with an average value of –0.10. Although this is not a typical 'area-wide' scheme, the results could be taken as similar to such a scheme, given the lack of alternative routes.

H1.2.2 Individual Route Tolling Schemes

A number of studies have been undertaken which examined the effects of individual toll road schemes, particularly in the US (Table H2). Many of these have been undertaken at river crossings and on toll roads where opportunities to divert to other routes are often limited. The following results refer principally to the effects of toll increases on traffic levels on the existing toll route.

Most of the studies demonstrated that, while increases in tolls lead to a reduction in traffic, the response is generally inelastic. Elasticity estimates typically range from –0.05 to –0.30. While most of these studies do not specify a time horizon, most estimates are likely to reflect the SR responses.

Travers Morgan (1992b) further separated the routes into 'reasonable alternative' route options and 'difficult alternative' route options and derived average elasticities of –0.26 and –0.13 respectively.

Very few studies disaggregated elasticities by time of day of travel, with the exception of a before and after study by Atkins (1982, cited in Wentworth & Beresford 1998) which sought to segment the market according to peak and off-peak travel. Values ranged from –0.12 to –0.37 for the peak and –0.10 to –0.44 for the off-peak, i.e. findings on relative elasticities for peak versus off-peak periods were inconclusive.

H1.3 Australian and New Zealand Estimates

H1.3.1 Area-wide Tolling Schemes

Currently there are no area-wide toll schemes in Australia or New Zealand.

H1.3.2 Individual Route Tolling Schemes

Very few studies are available that have examined the effect of a toll on individual routes in Australia or New Zealand (Table H3). Luk & Lim (1992) undertook a comprehensive before and after analysis of toll schemes on the Sydney Harbour Bridge, Brisbane's Gateway Bridge and Melbourne's Westgate Bridge. Values of -0.03 (Gateway) and –0.02 (Harbour Bridge) were estimated immediately after the tolls were introduced, compared to a value of –0.13 after 3 months after opening (Harbour Bridge). This is a value not too dissimilar to the value of –0.10 estimated by Travers Morgan (1990b).

For Melbourne's Westgate Bridge, a 30% increase in toll resulted in a 10% decrease in traffic (elasticity –0.33); while subsequent removal of the toll resulted in a 21% increase in traffic (expressed as an elasticity of –0.21). However, the major effect in this case most likely reflected the diversion to/from other routes rather than increases/decreases in total traffic volumes.

H1.4 Conclusions

Our conclusions focus on price elasticities relating to area-wide tolling schemes, as conclusions relating to tolls on individual routes are likely to be very specific to the route in question and not readily transferable.

The main conclusions relating to area-wide toll elasticities that might be appropriate to urban areas in New Zealand are as follows:

- Typical short-run aggregate values would be around –0.15 (central estimate) with a likely range between –0.05 and –0.40. Actual values are likely to be sensitive to the level of toll charged.
- No clear evidence is seen on how these values would vary in the long run, although long-run values are likely to be greater than short-run values.
- Peak and off-peak values are likely to be broadly similar, although evidence is very limited on this aspect.

H2. Cross-Modal Effects

H2.1 International Evidence

Very few international studies have quantified the cross-modal impacts of toll charges on public transport demand (Table H4). As noted in Section H1.2.1, only Singapore set out to achieve a significant reduction in car use and hence modal shift towards public transport. For Singapore, Polak et al. (1994, cited in Halcrow Fox 1995) estimated a 12% increase in bus mode share (from 33% to 45%) for peak commuters when the Area Licensing Scheme was introduced.

Luk (1999) estimated a cross-elasticity of 0.17 in the SR (on introduction of the Scheme) and 0.80 in the LR (for subsequent toll increases). Luk commented that congestion tolls could only be as effective as petrol price increases in inducing modal shifts. As noted earlier, the results for Singapore may not be a good guide to likely responses in other cities.

These results compare to other studies which also observed cross elasticities of a similar order of magnitude (refer to McLynn & Goodwin (1973, cited in Cervero 1990) and Halcrow Fox (1995)).

Very limited international evidence is seen on diversion rates. In Milan, passenger surveys estimated that 41% of 'deterred' car users switched to public transport, although it was noted that this is an upper estimate (Polak et al. 1994, cited in Halcrow Fox 1995).

H2.2 Australian and New Zealand Evidence

Australian and New Zealand evidence on the impact of toll road schemes on public transport demand is minimal (Table H5). However, a stated intention survey in Wellington by Steer Davies Gleave (1993a) found that 69% of survey respondents said a toll charge would 'encourage' them to switch to public transport.

H2.3 Conclusions

As previously discussed, cross-elasticity estimates are much less transferable between centres than are direct elasticity estimates. In particular, the cross-elasticity will be very much influenced by the relative private and public transport mode shares. Therefore no attempt is made to recommend a specific cross-elasticity value for use in New Zealand urban centres. Rather, we focus on the 'diversion rate', i.e. the proportion of those people deterred from car use by the existence of area-wide tolling who would switch to public transport (in an urban situation).

Based on our review of the international evidence, and its transferability to the New Zealand situation, we estimate a diversion rate of 40% overall, i.e. 40% of the people 'deterred' from using the car would switch to public transport in New Zealand urban centres following the introduction of area-wide tolling in a region.

We note that:

- This proportion is rather higher than estimated in response to fuel price changes. This difference largely reflects that area-wide tolling is likely to have a CBD orientation, where relatively good public transport alternatives are available.
- This overall estimate could be disaggregated (e.g. peak versus off-peak) in similar manner to the estimate for fuel price changes (Section F2.4).

Table H1: Area-Wide Tolls Direct Elasticities – International Evidence

City/Country	Study Type and Period	Elasticity			Market Segment	Comments	Source	Rank
		Short Run	Long Run	Not Stated				
Singapore						Authors found that there was a decrease of 73% in the number of cars entering the charging area in the morning peak over the first 6 months of the scheme in 1975. By the early 1980s, traffic levels were 64% of the pre-scheme flows. Some of this decrease came about because drivers who previously drove into the restricted zone diverted around it or travelled earlier.	May & Mackie (1989), cited in Halcrow Fox (1993a)	←←
Singapore	Before and After (1976 to 1991)	-0.34				SD: -0.19	Luk (1999)	←←
Singapore	Surveys (1971 to 1991)			-1.50 -0.40	Initial toll increase Subsequent toll changes	Halcrow maintains that Singapore represents the most successful example of restricting car use by introducing tolling: morning peak flows in 1992 were approximately 50% of their level before the Area Licensing Scheme was introduced in 1975.	Polak et al., cited in Halcrow Fox (1995)	←←
Milan	Surveys					Experimented in area wide tolling in 1985. Car traffic was reduced by between 40% and 55% in the morning peak period.	Halcrow Fox (1995)	←←
Olso	Two Wave Panel Study (1990)			-0.03 to -0.04		This study was conducted in connection with the opening of the Oslo toll scheme.	Ramjerdi (1994)	←←
Olso	Implied Elasticity			-0.14		Estimated reduction in car journeys was 5%.	Halcrow (1995)	←←
Bergen	Implied Elasticity			-0.21		Estimated reduction in car journeys was 6% to 7%.	Halcrow (1995)	←←
Norway						Yau found that the morning peak period toll would significantly reduce peak period traffic (by more than 20%) and would generate substantial net economic benefits.	Yau (1992), cited in Halcrow Fox (1995)	←

Table H2: Individual Route Tolls Direct Elasticities – International Evidence

City/Country	Study Type and Period	Elasticity			Market Segment	Comments	Source	Rank
		Short Run	Long Run	Not Stated				
Indonesia	Before and After (1979 to 1999)	-0.01 to -0.85				Range of (arc) elasticity estimates.	Hasanudin & Astati (1998)	
Indonesia	Before and After (1983)	-0.23 to -0.36				Values derived from traffic count data on various Indonesian toll roads.	Travers Morgan (1992b)!	←
New York	Time Series (1979 to 1990)	-0.10				Analysis was undertaken for 8 toll facilities on most of the 6 bridge and 2 tunnel crossings in New York. Results were statistically significant. Values ranged from –0.03 to -0.50.	Hirschman et al. (1995)	←←
USA	Literature Review			-0.20		General commentary about tolls in the US. The author notes that toll elasticities are generally less than -0.20 for toll increases up to 100%.	Urban Transportation Monitor (2000)	←
UK				-0.08			Dartford Tunnel Joint Committee (1984), cited in Wentworth & Beresford (1998)	←
UK	Before and After	-0.12			Peak Dec 1979	Author notes that the variation in the elasticities could be due to the proximity of Christmas to the first toll increase and that the peak increase in November 1980 was double the previous rise.	Atkins (1982), cited in Wentworth & Beresford (1998)	←
		-0.37			Peak Nov 1980			
		-0.10			Off-Peak Dec 1979			
		-0.44			Off-Peak Nov 1980			
Norway				-0.22 to -0.80			Jones & Hervik (1992), cited in Wentworth & Beresford (1998)	←
US	Before and After	-0.08			Pennsylvania	Passenger cars (-1.9% traffic change)	Various Turnpike Authorities, cited in Traffic Quarterly (1981)	←
		-0.13			New Jersey	Passenger cars (-2.5% traffic change)		
		-0.31			Indiana	Passenger cars (-6.2% traffic change)		
		-0.18			Massachusetts	Passenger cars (-5.5% traffic change)		
		-0.13			Florida	All Vehicles (-3.2% traffic change)		
		-0.30			West Dade	All Vehicles (-4.6% traffic change)		
		-0.28			Holland East-West	All Vehicles (-6.9% traffic change)		
		-0.03			Bee Line	All Vehicles (-0.09% traffic change)		
		-0.21			Cimmason	Passenger cars (-3.6% traffic change)		
		-0.30			HE Baily	Passenger cars (-5.1% traffic change)		
		-0.25			Indian Nation	Passenger cars (-2.3% traffic change)		
		-0.25			Muskogee	Passenger cars (-4.5% traffic change)		
		-0.31			Turner	Passenger cars (-3.4% traffic change)		
San Francisco				-0.10			Harvey (1994)	

Table H2: Individual Route Tolls Direct Elasticities – International Evidence

City/Country	Study Type and Period	Elasticity			Market Segment	Comments	Source	Rank
		Short Run	Long Run	Not Stated				
USA				-0.31	Cape May		Travers Morgan (1992b)	←
				-0.26	Delaware - passengers			
				-0.13	Delaware - commuters			
				-0.15	Chesapeake Bay			
				-0.24	Queens Midtown			
				-0.22	Henry Hudson			
				-0.14	Triborough			
				-0.07	Verrazano-Narrows			
				-0.05	Throngs Neck and Bronx Whitestone			
USA				-0.26	Reasonable route options		Travers Morgan (1992b)	←←
				-0.13	Difficult route options			

Table H3: Individual Route Tolls Direct Elasticities – Australian and New Zealand Evidence

City/Country	Study Type and Period	Elasticity			Market Segment	Comments	Source	Rank
		Short Run	Long Run	Not Stated				
Brisbane (Gateway Bridge)	Before and after	-0.03			Toll 3 weeks after opening	Included all traffic volumes. Note that 3 weeks after opening there was a 0.8% decrease in demand.	Luk & Lim (1992)	
Melbourne (Westgate Bridge)	Before and after	-0.33 -0.21			Value measures the effect immediately after toll increase Immediately after toll removal	Includes private vehicle volumes. Major effect is likely to be diversion to/from other routes.	Luk & Lim (1992)	
Melbourne (Westgate Bridge)				-0.30			Travers Morgan (1990b)	
Melbourne (Westgate Bridge)		-0.21			Effect of a toll removal		Thompson & Vincent, cited in Travers Morgan (1990b)	
Sydney (Harbour Bridge)		-0.10			AM Peak	Effect of a toll on the Sydney Harbour Bridge. Author noted that some traffic diverted to Gladesville Bridge as a result of the increase.	Travers Morgan (1990b)	
Sydney (Harbour Bridge)	Before and after	-0.02 -0.13			Immediately after toll introduced Effect 3 months after opening	Considered all traffic volumes.	Luk & Lim (1992)	
Sydney	Network modelling			-0.27 to -0.40		Future year modelling effects on road traffic as a result of toll increases.	Booz Allen Hamilton (2002a)	

Note: No Australian and New Zealand area-wide toll schemes.

Table H4: Tolls Cross-Modal Elasticities – International Evidence

City/Country	Study Type and Period	Elasticity			Market Segment	Comments	Source	Rank
		Short Run	Long Run	Not Stated				
Bergen (Norway)	Stated intention survey					A case study of Toll Rings in Bergen, Norway, examined the impact of a toll scheme on trip making behavior and mode choice decisions. The study concluded that traffic crossing the control ring decreased 6% to 7% after the introduction of tolls. In particular, car use reduced significantly by those who travelled to work by car occasionally, utilising PT or car sharing the remainder of the time.	Steer Davies Gleave (1995)	←←
Singapore	Before and after	0.17	0.80		The short run value was derived for the 1975 ALS introduction and a long run value for the 1976 and 1980 toll increases	The impact of the congestion toll was initially small, however, the impact became larger as the toll increased. The author notes that the Additional Registration Fee (which increased to 175% of the market value in 1983) and ALS may have helped the increase in bus mode share. Luk concluded that, from the experience in Singapore, congestion tolls could only be as effective as petrol price increases in inducing modal shifts. Before ALS, public transport mode share (bus only) to the CBD was 33%. It increased to 46% in 1976, 69% in 1983 and 66% in 1988 (when the MRT became operational).	Luk (1999)	←←←
US				0.32 to 0.41		Author concludes that higher auto tolls produced transit ridership increases.	McGlynn & Goodwin (1973), cited in Cervero (1990)	←
Singapore						Found that area-wide tolling in Singapore increased bus patronage. The share of work trips by bus increased from 33% before ALS to 69% by 1983.	May & Mackie (1989), cited in Halcrow Fox (1993a)	←
Singapore	Surveys (1975-92)					The immediate impact of ALS was to increase the proportion of morning peak commuters travelling by bus from 33% to 45%.	Polak et al., cited in Halcrow Fox (1995)	←←
Milan	Surveys (1985)					Surveys of car drivers who rescheduled their trips by time of day and mode when confronted with a peak period restriction found that 41% of deterred car users switched to public transport. Author noted that the switch to public transport could have been lower if there was an increase in car occupancy – but the surveys undertaken were not detailed enough to prove this.	Polak et al., cited in Halcrow Fox (1995)	←←

Table H5: Tolls Cross-Modal Elasticities – Australian and New Zealand Evidence

City/Country	Study Type and Period	Elasticity			Market Segment	Comments	Source	Rank
		Short Run	Long Run	Not Stated				
Wellington	Stated Intention Survey					Survey respondents were asked "which options would encourage you to use public transport". 69% of respondents stated a toll charge would encourage public transport use (a higher proportion than for other charging options offered).	Steer Davies Gleave (1993a)	←

Appendix I: Parking Charges

I 1. Direct Effects

I 1.1 Introduction

This Appendix I sets out our review of the evidence on the direct effects of parking pricing policies on:

- Car travel demand, i.e. direct demand elasticity; and
- Public transport travel demand, measured through either cross-elasticities or diversion rates.

Our review focuses on the impacts of area-wide parking pricing policies on travel behaviour. However, such schemes are rarely implemented and hence the directly relevant evidence is limited. Similar to the case of toll charges (Appendix H), most parking pricing schemes apply only to particular parking sub-sectors or sometimes individual sites, rather than comprehensively over an area. Where only certain sub-sectors or sites are affected, a common response is to park elsewhere in the area rather than to change travel mode.

In interpreting the results from the range of studies of parking pricing impacts, the following factors should be borne in mind:

- Parking policies are normally instituted as part of a package of traffic restraint measures rather than in isolation. This can make it very difficult to determine the separate effect of the parking policies.
- Results are likely to be case-specific, depending on the range and quality of alternatives to the car parks which have their prices changed.
- Effects have been measured in different ways at different locations, making comparison of results very difficult. Typical measures include:
  - Changes in use at particular sites,
  - Change in the number of solo drivers,
  - Changes in the total number of car trips.

Moreover, the effects of parking charges on travel demand will be limited in circumstances where:

- A low proportion of car users pay to park;
- Car travel is through-travel, with car travellers having non-city/town centre destinations; and
- Employers subsidise or reimburse employees' parking costs.

I 1.2 International Evidence

Much of the literature on the effects of parking price changes on car travel demand relates to CBD commuters, with very limited evidence on non-commuter travel demand. Table I 1 provides details of the international evidence available, which can generally be divided into two main groups:

- North American literature, which focuses on total car travel demand (or solo driver demand) by commuters (denoted by Em in the tables); and
- UK literature which mostly relates to parking demand at a site or area (denoted by Es in the tables).

The North American literature is most relevant to this review since it focuses on total car travel demand.

Typically, car travel demand elasticities with respect to parking prices (principally related to commuters) are in the range of –0.10 to –0.60. Most of the evidence relates to SR changes, and it is unclear whether LR effects will differ substantially from these, and if so in what way. Some of the key findings from the North American literature are as follows:

- Shoup & Willson (1992) conducted a range of 'before and after' and 'with or without' studies of commuter solo driver responses to parking in various areas throughout Los Angeles (LA) and Ottawa CBD. Values ranged from –0.08 in LA suburban areas to –0.23 in areas near LA CBD, with an average of –0.16 over six case studies. Moreover, the results showed that removing employer-paid parking reduced solo driver share by between 18% and 81% depending on the circumstances.
- Pickrell & Shoup (1980) summarised several North American studies and found that elasticities varied from –0.24 to –0.36 with respect to parking costs. They also compared mode choice at LA government sites involving free and period parking, deriving a total car travel elasticity of –0.20.
- Kocur et al. (1982) conducted mode choice studies that examined car traffic responses across a range of US cities. Values ranged from –0.06 to –0.11 (point estimates).
- Analysis of car travel demand resulting from removing free parking for a company in Los Angeles by Surber et al. (1984), cited in Feeny (1989), found an elasticity of –0.10.
- Transport Canada (1978, cited in Willson & Shoup 1990, Feeney 1989), estimated an elasticity value of –0.24 in response to substantial parking charges imposed on Federal Government employees in Ottawa. However, the significance of the result is somewhat obscured by other simultaneous measures. Re-analysis of the data (Feeney 1989) indicates an elasticity of car travel with respect to parking price of –0.11.
- Miller & Everett (1982, cited in Feeney 1989), examined the imposition of parking charges for US Federal Government workers in Washington DC. This resulted in 1% to 10% reduction in car driver mode share in the CBD, and a 2% to

4% reduction in car driver mode share at suburban sites. The magnitude of the effects depended on supply/cost of parking, base mode shares and the availability of alternatives. The price changes had the greatest effects at central area locations with good public transport accessibility. Re-analysis of the data by Feeney (1989) indicated car trip price elasticities in the range 0 to –0.32 (average –0.12) for central area sites and 0 to –0.03 for suburban sites.

- In Toronto, Gillen (1978, cited in Axhausen & Polak 1991) found that the probability of car use for work trips varied as distance from the destination increased. Values ranged from –0.24 (up to one block) to –0.41 (up to three blocks). Gillen (1978) also estimated an unweighted average elasticity of –0.31 for travel in Toronto.

No direct car travel elasticity estimates were found in the UK/European literature, although a slight change in car driver mode share was reported in a couple of studies:

- A before and after study in Munich-Lehel found that the introduction of residential parking permits resulted in a decline in car driver travel by employees of around 27%, with car driver mode share declining from 44% to 32% (Topp 1991, cited in Halcrow Fox 1995).
- A 1994 study in the UK by TRRL (cited in Halcrow Fox 1995) found that doubling parking charges led to a 20% decline in traffic levels to the affected sites in the central areas of Reading and Bristol. This translated into an overall reduction of 2% to 3%. An interesting feature was that the effect in the central area was greater in the off-peak than the peak, reflecting that a higher proportion of people pay to park in the off-peak, and that they may have the option of travelling to a different destination (e.g. shopping trips).

I 1.3 Australian and New Zealand Evidence

Very few Australian and no New Zealand studies have examined the effects of changes in parking charges on car travel demand (Table I 2). Of the evidence available, there is a considerable range of results and whether the study was referring to parking demand in a site or area, or to total car travel demand was not always clear. Moreover, it was often unclear whether these estimates were SR or LR, although most appear to be SR.

Chambers & Ker (1990) concluded that typical parking price elasticities range from –0.20 to –0.40, which is consistent with the OTPP estimate of –0.30 (OTTP 1994, cited in Bray 1995). This compares to substantially lower elasticity estimates by Commeignes (1991) and Shepherd (1972) in their Sydney studies. On the other hand, Hensher & King (2001) estimated higher values, at around –0.5 or greater.

I 1.4 Conclusions

It is misleading to suggest that any one parking price elasticity could be used with confidence in analysing parking price policies. The elasticity will depend on the nature and type of parking spaces affected by a particular price change and the opportunities for using alternative parking facilities. These opportunities will differ by time of day and the elasticities themselves would differ for, say, shoppers as opposed to commuters. They would also depend on the physical measures adopted for controlling parking spaces in addition to the price charged.

As noted most of the evidence available related to SR changes. It is not clear whether long-term effects will differ substantially from these and, if so, in what way.

For strategic assessment purposes in major New Zealand urban centres, we suggest a 'best estimate' elasticity of commuter car travel with respect to CBD parking changes of –0.30. This should be applied to that segment of the market affected by such charges. This value is applicable only to CBD trips as it is assumed parking restraint is not applied elsewhere.

I 2. Cross-Modal Effects

I 2.1 International Evidence

Very limited evidence is available internationally on the effect of changes in parking charges on public transport demand (Table I 3). Again, the cross-modal effect is best represented in terms of the proportion of people deterred from car usage who transfer to public transport and this has been reported when possible. Results however were wide-ranging and differed substantially between studies. Key findings included:

- Kocur et al. (1982) conducted a mode choice experiment in 1980 which examined bus demand with respect to parking across various US urban centres and found values ranged from 0.13 to 0.19.
- Brown (1972, cited in various authors, see Table I 2) estimated a value of 0.30 for Vancouver, from SP studies.
- Commeignes (1991) examined the effects of a $1/day surcharge for AM peak parking in Madison (US) which resulted in a 5% to 8% increase in car commuters switching to bus or park and ride.
- In Europe, Gantvoot (1984) examined the closure of a car park in The Hague town centre and found that 78% of the suppressed car drivers (i.e. 19%) switched to public transport. This figure translates into an overall shift to public transport of 14% of the previous car park users.
- In Oxford, parking restraint in the CBD resulted in a 10% shift from car to public transport (TRRL 1980).
- A before and after study in Munich-Lehel found that the introduction of residential parking permits resulted in an increase in public transport mode share for employees from 39.7% to 47.3% (Topp 1991, cited in Halcrow Fox 1995).
- An SP study in Bristol (Ampt & Jones 1992) into the effects of banning cars in the city centre, found that 50% of those affected would travel by bus all the way, 28% would drive to the bus or train.
- A stated response study in Dublin by Halcrow Fox (1993b) found 40% of respondents stated they would change mode following a 40% increase in parking charges, while 68% stated they would change mode following an 80% increase in parking charges.

- Halcrow Fox (1993b) suggests that the public transport diversion rate in response to increased parking charges is likely to be as high as 50% to 75%, particularly in central areas where public transport is likely to provide the closest alternative.

I 2.2 Australian and New Zealand Evidence

Not surprisingly there are very few studies in Australia and New Zealand that have quantified the public transport demand implications of increased parking charges (Table I 4). The results primarily relate to the CBD, principally by commuters. Generally the diversion to public transport appears low, although this is difficult to quantify. In Adelaide, for example, OTPP (1994, cited in Urban Transport Working Group 1996) suggested that a 50% increase in CBD car parking charges could result in a 15% decline in car travel, and that public transport travel could increase 2%.

I 2.3 Conclusions

As previously discussed, cross-elasticity estimates are much less transferable between centres than are direct estimates. We therefore do not recommend a specific cross-elasticity value for use in New Zealand urban areas. Instead we have focused on the relevant 'diversion rates', i.e. the proportion of people deterred from car use by increased parking charges who would switch to public transport.

Based on the very limited evidence available, we suggest the following assumptions be adopted for use in New Zealand urban areas on the proportion of travellers deterred from car use by parking charges who would shift to public transport.

- Regional CBD – commuters (peak periods): 75%
- Regional CBD – others (off-peak periods): 50%
- Suburban CBD – commuters (peak periods): 50%
- Other areas: not addressed, but likely to be much lower.

These diversion rates are high relative to those estimated for other travel time/cost components. This is consistent with the affected trips being to/from CBD areas, which have relatively good public transport accessibility.

These rates are essentially SR diversion rates. In the LR, we anticipate that the rates are likely to be lower as a wider range of alternative responses becomes feasible (e.g. changing employment location).

Table I 1: Parking Charges Direct Elasticities – International Evidence

City/Country	Study Type and Period	Elasticity	Market Segment	Comments	Source	Rank
US/Canada	Literature Review	-0.24 to -0.36		Typical range of elasticity estimates (Em).	Pickrell & Shoup (1980)	←←
Ottawa (Canada)	Before and After (1975)	-0.11	Solo work trips (estimate is based on re-analysis of the original data by Feeney)	37,500 Federal Government employees had substantial parking charges imposed in 1975. The proportion using car for journey to work reduced from 35% to 27%. This implies a commuter parking elasticity of -0.24. Also noted that the significance of the result is somewhat obscured by other simultaneous measures (Em).	Transport Canada (1978), cited in Willson & Shoup (1990), and Feeney (1989)	←←
Various	Literature Review	-0.10 to -0.68	Solo Driving	The evidence from the various case studies showed that ending employer-paid parking reduced the number of solo drivers by between 19% and 81% and reduced the number of cars driven to work by between 15% and 38% (Em).	Willson & Shoup (1990)	←←
US/Canada		-0.16	Average of six case studies of commuters (range -0.08 to -0.23)	Results reflect how employer-parking subsidies affect commuter mode choice. Authors assemble and summarised existing well-documented before and after and with and without studies of how employer-paid parking affects travel behaviour based on their earlier review (i.e. refer to Willson & Shoup, 1990). This average value of -0.16 reflects a 40% decline in solo driver share and a 27% decline in car trips (Em).	Shoup & Willson (1992)	←←←
Washington (USA)	Before and After (1979)	-0.0 to -0.32 (average -0.12) -0.0 to -0.03	Central areas Suburban sites	Imposition of parking charges for US Federal Government workers in Washington DC resulted in 1% to 10% reduction in car driver mode share at central area sites and 2% to 4% reduction in car driver mode share at suburban sites (Em).	Miller & Everett (1982), cited in Feeney (1989)	←←
San Francisco (USA)	Mode Choice Modelling			Author suggests, although without statistical precision, that parking costs are weighted more heavily than mileage related or car maintenance costs.	McFadden (1974), cited in Feeney (1989)	←←
Vancouver (Canada)	Stated Preference	-0.36	Commuters	(Em)	Brown (1972), cited in Feeney (1989)	←←
Toronto (Canada)		-0.31	Commuters	Analysis of the effect on parking charges on car transit choice. Developed a weighted parking price elasticity of the probability of car use (Em).	Gillen (1977), cited in Feeney (1989)	←←
San Francisco (USA)	Before and After (1970-72)	-0.25	Average price elasticity over a number of car parks	Examined the effects of a parking levy in San Francisco. Author noted that there was a wide range of elasticity estimates at individual car park locations (Es).	Kulash (1974), cited in Haworth & Hilton (1982)	←←

Table I 1: Parking Charges Direct Elasticities – International Evidence

City/Country	Study Type and Period	Elasticity	Market Segment	Comments	Source	Rank
San Francisco (USA)	(1970 to 1973)	-0.27 -0.26 -0.91 -0.80 -0.25 -0.23 -0.20 -0.31 -0.38	Commuter (1970/71) 25% tax increase Commuter (1971/72) 25% tax increase Commuter (1972/73) 10% tax decrease Shopper (1970/71) 25% tax increase Shopper (1971/72) 25% tax increase Shopper (1972/73) 10% tax decrease All (1970/71) 25% tax increase All (1971/72) 25% tax increase All (1972/73) 10% tax decrease	Results are based on 13 municipally operated garages – examination of the full tax effect over a two-year period for different market segments (Es?).	Kulash (1974), cited in Pratt et al. (2000)	←
Los Angeles (USA)	Before and After	-0.10 -0.68	All Solo Driver	Elasticity of car travel demand resulting from ending free parking for employees at a company in downtown Los Angeles (Em).	Surber et al. (1984), cited in Feeney (1989)	←←
Los Angeles (USA)		-0.29 -0.20	Solo driver (commuter travel) Total car travel	Comparison of mode choice at government parking sites for receiving free and paying parking (Em).	Pickrell & Shoup (1980)	←←
San Francisco (USA)		-0.30		Examined the effect of a tax on parking for all trips. Resulted in around a 2% reduction in CBD traffic levels (Em).	Ellis (1977)	←←
USA		-0.30	Work trips	Estimated the probability of car use for work trips wrt parking charges (Em).	Westin & Gillen (1978), cited in Feeney (1989)	←←
London (UK)		-0.30 to -0.60 -0.0 to -0.60 -0.40 to -1.20	Short Stay (0-2 hrs) Medium Stay (2-8hrs) Long Stay (8+hrs)		May (1977), cited in Haworth & Hilton (1982)	←
Coventry (UK)	(1976 to 1980)	-0.05 to -0.20 -0.10 to -0.40 -0.15 to -0.55 -0.20 to -0.75	Up to 2hrs 2 to 4hrs 4 to 6hrs 6+hrs	Analysis of municipal parking in Coventry – analysis of responses to short stay parkers to increases in parking charges (Es).	Redknap, cited in Haworth & Hilton (1982)	←
Manchester (UK)	Literature Review	-0.10 -0.30 -0.60 -1.20	0 to 3hrs 3 to 5hrs 5 to 7hrs 7+ hrs	Authors assumed the following elasticities for car parks in central Manchester based on the UK evidence available (Es).	Haworth & Hilton (1982)	←

Table I 1: Parking Charges Direct Elasticities – International Evidence

City/Country	Study Type and Period	Elasticity	Market Segment	Comments	Source	Rank
USA	Mode Choice Modelling (1980)	-0.06 to -0.11		Examined the demand for 'parking' with respect to parking costs across the urban centres of Milwaukee, Madison, Fox River Valley and other cities (Em).	Kocur et al. (1982)	←←
Westminster (UK)	(1970-76)	-0.03 to -2.30 -0.60 to -1.10	Short Stay All Day	Analysis of the performance of 9 car parks in the city of Westminster (Es).	Wright & Holden (1977), cited in Haworth & Hilton (1982)	
Croydon (UK)		-0.50 -2.00	Long stay Long stay (high charges)	Analysis of parking returns in Croydon over a 6-year period. Study found short-stay parking demand was relatively inelastic (Es).	Jackson & Pierce (1978), cited in Haworth & Hilton (1982)	
Vancouver (Canada)	Stated Preference	-0.32		Doubling of daily parking charges – log arc formulation. Also suggests that a 3% shift to public transport for every 10% increase in parking charges (Em).	Brown (1972), cited in Feeney (1989)	←
Washington (USA)	Before and After	0 to -0.32 0 to 0.03	Central area Suburban	Linear arc price elasticity of demand for car use at various work sites. Author says the variation is in response to differences in alternative parking supply (Em).	Miller & Everett (1982), cited in Feeney (1989)	←
London (UK)		-0.74	Long stay	Typical value estimated for long-stay parking at a site (Es).	Carr (1977), cited in Haworth & Hilton (1982)	
Munich-Lehel	Before and after			Following the introduction of residential parking permits, public transport mode share for employees increased from 40% to 47%. Car driver mode share declined from 44% to 32%.	Topp (1991) cited in Halcrow Fox (1995)	←
UK	Transport Modelling (1994)			Study found doubling parking charges had a significant effect on traffic levels in the central areas. Reductions of over 20% in the central area were forecast in Bristol and Reading where parking charges were already high (i.e. overall reduction of 2-3% was estimated). An interesting feature was that the effect on the central area was greater in the off-peak since a larger proportion of people pay to park in off-peak periods.	TRRL, cited in Halcrow Fox (1995)	←
Various	Literature review	-0.30 -0.10 to -0.60	Average Range	Results reflect area-wide changes in parking. Reported values should be considered as arc elasticities (Em).	Pratt et al. (2000)	←←
Los Angeles (USA)	Before and after	-0.32	Elimination of free parking for solo drivers	(Em)	Soper (1989), cited in Willson & Shoup (1990)	←

Table I 2: Parking Charges Direct Elasticities – Australian and New Zealand Evidence

City/Country	Study Type and Period	Elasticity	Market Segment	Comments	Source	Rank
Sydney	1970	-0.05	Mainly commuters	Examined the impact on demand resulting from a doubling of Sydney City Council Parking Station fees (Em).	Commeignes (1991)	←←
Sydney	Stated Preference (1976)	-0.60	Mainly commuters long stay parking	SP survey of users at 4 parking stations in Sydney Central area. If charges were to increase 50% then usage was reported to fall 30%; but over half the deterred travellers would continue to make their trip by car, at least part way (Es).	Paterson Urban Systems (1977)	←
Australia	Literature Review	-0.20 to -0.40		Typical range for parking price elasticities.	Chambers & Ker (1990)	←←
Melbourne	Cross-sectional Analysis	-0.09	Peak CBD work trips		Shepherd (1972)	←
Adelaide		-0.30	CBD car trips	Author suggests that a 50% increase in the cost of car parking in Adelaide CBD could result in a 15% decline in car trips to the CBD (Em).	OTPP (1994), cited in Bray & Ass. (1995), and Urban Transport Working Group (1996)	
Sydney	Stated Preference (1998)	-0.54 -1.02 -0.48	Parking close in the CBD Parking elsewhere in the CBD Parking in the CBD fringe	Results suggest that greatest sensitivity is parking elsewhere in the CBD: those who choose to park as close as possible to their final destination are least sensitive to parking rates as are fringe parkers when compared to other parkers in the CBD (Es).	Hensher & King (2001)	←←

Table I 3: Parking Charges Cross-Modal Elasticities – International Evidence

City/Country	Study Type and Period	Elasticity	Market Segment	Comments	Source	Rank
Vancouver (Canada)	Stated preference	0.30			Brown (1972), cited in Pickrell, Pickrell & Shoup (1980), Feeney (1989)	←
USA	Mode choice modelling	0.13 to 0.19		Analysis across various urban areas in the US including Milwaukee, Madison, Fox River Valley and other cities.	Kocur et al. (1982)	←←
USA	Surveys of travel behaviour			Analysis of 20 cities across the USA found that cities with an interventionist approach to parking policies (i.e. high parking prices and limited supply), a frequent transit service and a high probability that travellers pay for parking are most likely to have high transit ridership figures.	Milder et al. (1997)	
Canada	Surveys of travel behaviour			Surveys revealed a strong relationship between peak period modal split to public transport and the supply of downtown parking (i.e. the proportion of downtown commuters using public transport is inversely proportional to the ratio of parking stalls per downtown employee.	Morrall & Bolger (1996)	
Munich-Lehel	Before and after			Following the introduction of residential parking permits, public transport mode share for employees increased from 40% to 47%.	Topp (1991), cited in Halcrow Fox (1995)	←
Paris	Stated response			A stated response of Paris commuters found that 20% would change to bus/tram if their usual free on-street parking space was not available.	Bieber (1983)	←
Oxford				Study found that severe parking restraint on public spaces in the CBD resulted in a 10% shift from car to bus for CBD trips.	TRRL (1980)	←
Bristol	Stated response			SP responses in Bristol if cars were banned in the city centre found 50% would travel by bus all the way, 22% drive and get the bus, and 6% drive and get the train.	Ampt & Jones (1992)	←

Table I 3: Parking Charges Cross-Modal Elasticities – International Evidence

City/Country	Study Type and Period	Elasticity	Market Segment	Comments	Source	Rank
Dublin	Stated response			40% of respondents stated that they would change mode following a 40% increase in parking charges and 68% stated they would change mode following an 80% increase in parking charges.	Halcrow Fox (1993b)	←
USA (West Coast)				Results of analysis showed that parking price has the greatest effect on travel behaviour of residents in the urban core, near core and outer suburbs of large cities; its effect is greatest when transit service levels are high.	Dueker et al. (1998)	
The Hague				This study into the effects of car park closure in the Hague found that 81% of previous car drivers continue as car drivers. Of the suppressed car drivers 78% change to public transport.	Gantvoot (1984)	←
Madison (USA)				A surcharge of $1 per day on car parking in the AM peak resulted in 5% to 8% of car commuters switching to bus or park-and-ride.	Commeignes (1991)	←

Table I 4: Parking Charges Cross-Modal Elasticities – Australian and New Zealand Evidence

City/Country	Study Type and Period	Elasticity	Market Segment	Comments	Source	Rank
Melbourne (Australia)	Cross-sectional (1964)	0.02	Peak work CBD trips		Shepherd (1972)	←←
Canberra	Stated Preference	0.20			DJA-Maunsell (1992)	
Adelaide (Australia)	Transport Modelling	0.04		Modelling suggests that a 50% increase in car parking charges in Adelaide CBD could result in a 15% decline in car travel. Author suggested that public transport travel demand might increase 2%.	OTPP (1994), cited in Urban Transport Working Group (1996)	←←
Sydney (Australia)	Stated Preference			Survey of users (mainly commuters) of 4 parking stations in Sydney CBD found that if charges were to increase 50%, then usage was reported to fall 30% (-0.60). Of the people who would stop using the facility, 25% would change to public transport.	Paterson Urban Systems (1977)	

Appendix J: Car In-Vehicle Time

J 1. Direct Effects

J 1.1 Introduction

This Appendix J sets out the New Zealand and international evidence available on the direct effects of changes in car in-vehicle time on:

- Car travel demand (direct elasticity); and
- Public transport travel demand, through cross-elasticity or diversion rate estimates.

Few studies are available among the New Zealand, Australian and international evidence that have quantified these impacts. The findings of our review are detailed below.

J 1.2 International Evidence

Few studies available have examined the impact of changes in in-vehicle time on car travel demand.

J 1.2.1 Overall Estimates

Based on the evidence from studies in both North America and Europe (Table J1) the most likely elasticity values appear to range from around –0.3 in the SR to –0.6 in the LR (Goodwin 1996). However, SACTRA (1994) estimated more elastic values, of about –0.50 for the SR and –1.0 for the LR.

In their recent review of European studies, de Jong & Gunn (2001) found conflicting evidence on relative SR and LR values: for all trip purposes together, LR elasticities (–0.29) were much lower than SR elasticities (–0.60) when measured in terms of car trips; but LR values (–0.74) were much higher than SR values (–0.20) when measured in terms of car kilometres.

J 1.2.2 Disaggregate Estimates

Often the market was segmented according to the trip purpose, particularly work trips. However, based on the evidence available, it is unclear whether work travel is more or less sensitive than other travel purposes. There was also wide variation between studies, which made it very difficult to formulate sensible conclusions.

J 1.3 Australian and New Zealand Evidence

While no New Zealand evidence was found, the Australian literature (Table J2) revealed SR estimates of a similar order of magnitude to those found internationally, although many of the studies did not specify a time horizon. Most estimates fell within the range of –0.10 to –0.40.

Most of these estimates referred to peak CBD trips, particularly work trips. Major findings included:

- Mode choice modelling of work trips in Sydney by Madan & Groenhout (1987) estimated a value of –0.17.
- Cross-sectional analysis of CBD work trips in Perth by Shepherd (cited in Travers Morgan 1979) found a point elasticity of –0.20.
- A cross-sectional analysis by Smith (cited in Travers Morgan 1979) revealed a point elasticity of –0.34 for CBD work trips in Sydney.
- Hensher (cited in Industry Commission 1994) examined the demand for commuter trips in Sydney and estimated an elasticity of –0.12 for car driver trips and –0.38 for car passenger trips.
- A cross-sectional analysis by Shepherd (1972) found an elasticity of –0.35 for peak CBD work trips in Melbourne.

J 1.4 Conclusions

On a basis of our review, we consider the following in-vehicle time elasticities as appropriate for the New Zealand market:

- SR elasticity: central estimate –0.30, typical range –0.15 to –0.50.
- LR elasticity: central estimate –0.60, typical range –0.30 to –0.80.
- Evidence is inconclusive as to relative elasticities by trip purpose and time period, so assume no differences.
- Similarly evidence is inconclusive on relative elasticities for CBD v non-CBD trips.

J 2. Cross-Modal Effects

J 2.1 International Evidence

No direct evidence on the proportion of deterred car travellers who would switch to public transport in the event of increases in car in-vehicle time was found in the international literature. Evidence on the cross-elasticity effects was found in several studies (Table J3), including in particular:

- de Jong & Gunn (2001) estimated a SR cross-elasticity for all trips of 0.27, and a LR elasticity of 0.15 (surprisingly lower than the SR).
- Brand & Benham (n.d.) estimated a value of 0.20 for peak period transit demand.
- Algers et al. (1995) estimated a value of 0.22 for work trips and 0.15 for all trips.

J 2.2 Australian and New Zealand Evidence

Few studies in Australia and New Zealand have examined the sensitivity of public transport demand to car in-vehicle time. Most of the estimates relate to peak work trips, particularly to the CBD (Table J4).

The following cross-elasticities were estimated:

- Mode choice modelling in 1981 by Madan & Groenhout (1987) derived a cross-elasticity of 0.31 for transit travel to work in Sydney (with respect to 'highway' travel time).
- Similarly, in Perth, Shepherd (cited in Travers Morgan 1979) derived a value for peak CBD work trips of 0.24 from a cross-sectional study.
- Shepherd (1972) observed a much lower estimate of 0.09 from a cross-sectional analysis for peak CBD work trips in Melbourne in 1964.
- A cross-sectional analysis undertaken by Smith (cited in Travers Morgan 1979), also obtained a relatively inelastic value of 0.07 for CBD work trips.
- A mode choice experiment by Hensher (cited in Industry Commission 1994) found a rail demand cross-elasticity of 0.19 compared to 0.07 for bus demand in Sydney.

Again, the evidence was very limited on the proportion of deterred car travellers who would switch to public transport in the event of increases in in-vehicle time. An SP study by Booz Allen Hamilton (2002b) estimated this proportion to be as high as 56%.

J 2.3 Conclusions

Few studies in Australia and New Zealand, and not many more internationally, have examined the sensitivity of public transport demand to car in-vehicle time. Moreover, very little direct evidence is available on the 'diversion rates' to public transport by people deterred from car travel when in-vehicle time increases.

In terms of estimating appropriate diversion rates relevant to urban areas in New Zealand, our starting point would be the diversion rates derived in relation to changes in car travel costs (fuel, operating costs, etc.), i.e. an average diversion rate of 30% to public transport (Section F2.4). However, it could be expected that 'time-sensitive' people are less likely to switch from car to public transport than are 'cost-sensitive' people. On this basis, and lacking better information, we suggest an appropriate average diversion rate would be 20% in this case.

As in the case of car travel costs, we suggest the peak period diversion rate will be around twice the off-peak rate (broadly 30% and 15% respectively).

For a typical New Zealand mode split of 80% car : 20% public transport, and a SR direct elasticity of –0.30 (Section J 1.4), the 20% diversion rate implies an equivalent cross-elasticity of 0.24. This seems plausible in the light of the weight of Australian–New Zealand and international evidence.

Table J 1: Private Transport In-vehicle Time Direct Elasticities – International Evidence

City/Country	Study Type and Period	Elasticity			Market Segment	Comments	Source	Rank
		Short Run	Long Run	Not Stated				
Europe	Literature Review	-0.60	-0.29		All User Groups	Summary results (mean unweighted) of various European studies which were undertaken (generally) from 1985 onwards. Author notes that the range of values between studies varies. Car travel demand is measured in terms of trips.	de Jong & Gunn (2001)	←←←
		-0.62	-0.41		Commuting Trips			
			-0.30		Home-Based (HB) Business			
			-0.12		Non HB Business			
			-0.57		Education			
		-0.52	-0.57		Other			
Europe	Literature Review	-0.20	-0.74		All User Groups	Summary results (mean unweighted) of various European studies undertaken (generally) from 1985 onwards. Car travel demand is measured in terms of vehicle kilometres travelled (VKT). Author notes that the range of values between studies is varied.	de Jong & Gunn (2001)	←←
			-0.63		Commuting Trips			
			-0.61		Home-Based (HB) Business			
			-0.53		Non HB Business			
			-0.76		Education			
			-0.85		Other			
San Francisco (USA)	Mode choice modelling			-0.22	Work trips		McFadden (1974), cited in Gomez Ibanez et al. (1999)	←
Chicago (USA)	Choice Modelling			-0.47 to -0.64	CBD travel		Chu (2001)	←
Stockholm (Sweden)	Choice Modelling			-0.32	All Trips	Author also measured demand in terms of VKT and estimated work trip and all trip elasticites of -0.61 and -0.62 respectively.	Algers et al. (1995)	←←
				-0.38	Work Trips			
UK						This study of congestion effects found a mileage suppression of 24% and a 13% trip suppression. That is a doubling of journey time would lead to a 24% decline in mileage but only a 13% reduction in trips.	Christie (1995), cited in CIT (UK) (1996)	
Various	Literature Review	-0.17					National Transport Planning Framework – Urban Transport Working Group (1995)	
UK		-0.50	-1.00				SACTRA (1994)	←←
Various		-0.27	-0.57				Goodwin (1996)	←←

Table J 1: Private Transport In-vehicle Time Direct Elasticities – International Evidence

City/Country	Study Type and Period	Elasticity			Market Segment	Comments	Source	Rank
		Short Run	Long Run	Not Stated				
Toronto				-0.30 to -0.35	Work Trips	Elasticity reflects excess search time for parking.	Bajic (1984), cited in Feeney (1989)	←
Boston	Cross-sectional			-0.82 -1.02	Work Shopping		Charles River Associates, cited in Kemp (1973)	←
US				-0.22	Urban passenger		Small & Winston, cited in VTPI (2002)	←

Table J 2: Private Transport In-vehicle Time Direct Elasticities – Australian and New Zealand Evidence

City/Country	Study Type and Period	Elasticity			Market Segment	Comments	Source	Rank
		Short Run	Long Run	Not Stated				
Sydney	Discrete Choice Modelling (1981)	-0.17			Work Trips	This study extends earlier work by the authors who estimated a corresponding elasticity for work trips of -0.18.	Madan & Groenhout (1987)	←
Melbourne	Cross-sectional (1964)			-0.35	Peak CBD work trips	Point elasticity estimates	Shepherd (1972)	←
Perth	Cross-sectional (<1973)			-0.20	Peak CBD work trips	Point elasticity estimate	Shepherd, cited in Travers Morgan (1979)	←
Sydney	Cross-sectional (<1975)			-0.34	CBD work trips		Smith, cited in Travers Morgan (1979)	←
Sydney	Mode Choice Modelling			-0.12 -0.38	Car driver Car passenger		Hensher (1986), cited in Industry Commission (1994)	←

Table J 3: Private Transport In-vehicle Time Cross-Modal Elasticities – International Evidence

City/Country	Study Type and Period	Elasticity			Market Segment	Comments	Source	Rank
		Short Run	Long Run	Not Stated				
Europe	Literature Review	0.27 0.73	0.15 0.22		All Trips Commuting Other	Summary results (mean unweighted) of various European studies undertaken (generally) from 1985 onwards. Car travel demand is measured in terms of trips. Author notes that the range of values between studies is varied.	de Jong & Gunn (2001)	←←←
Europe	Literature Review			0.36	All trips	Summary results (mean unweighted) of various European studies undertaken (generally) from 1985 onwards. Car travel demand is measured in terms of vehicle kilometres travelled (VKT). Author notes that the range of values between studies is varied.	de Jong & Gunn (2001)	←←
San Francisco				0.36 0.41	Bus Rail		McFadden (1974)	←
Stockholm (Sweden)	Choice Modelling			0.15 0.22	All Trips Work Trips	Author also estimated demand in terms of VKT and found a work trip and all trip elasticity of 0.30 and 0.19 respectively.	Algers et al. (1995)	←←
Montreal	Time Series			0.42			Gaudry (1975)	←
Various	Literature Review	0.32					National Transport Planning Framework – Urban Transport Working Group (1995)	←
Baltimore (USA)	Cross-sectional			0.20	Peak	Constant elasticity	Brand & Benham (nd)	←

Table J 4: Private Transport In-vehicle Time Cross-Modal Elasticities – Australian and New Zealand Evidence

City/Country	Study Type and Period	Elasticity			Market Segment	Comments	Source	Rank
		Short Run	Long Run	Not Stated				
Brisbane	Joint RP/SP (2002)					Study found that 56% of 'deterred' passengers went to public transport, 22% to other modes and 22% did not travel.	Booz Allen Hamilton (2002b)	←←
Sydney	Discrete Choice Modelling (1981)	0.31			Work Trips	This study extends on earlier work by the authors who estimated a corresponding elasticity for work trips of 0.33.	Madan & Groenhout (1987)	←←
Melbourne	Cross-sectional (1964)			0.09	Peak work trips		Shepherd (1972)	←
Sydney	Mode Choice Modelling			0.19 0.07	Commuter Rail Commuter Bus		Hensher (1986), cited in Industry Commission (1994)	←
Perth	Cross-sectional			0.24	Peak work trips	Point elasticity estimate	Shepherd, cited in Travers Morgan (1979)	←
Sydney	Cross-sectional			0.07	Work trips	Point elasticity estimate	Shepherd, cited in Travers Morgan (1979)	←

Appendix K: Car Generalised Costs

K1. Introduction

This Appendix K sets out the evidence from the international literature on the direct elasticity of car demand with respect to the total 'generalised cost' of the car trip.

As noted in Chapter 2 of the report, the 'generalised cost' concept combines the weighted values of travel time, vehicle costs, toll prices, fuel taxes and parking prices. We note, however, that the literature often reports only partial generalised cost measures, such as total (weighted) time or total monetary costs. Also, in a number of cases generalised cost elasticities have been estimated from component elasticities, based on the proportion of the total generalised cost represented by that component: such estimates have been given lower weighting in our review.

Our review was unable to identify any Australian or New Zealand generalised cost estimates. Also, no evidence was identified relating to cross-modal effects (i.e. elasticity of public transport demand with respect to car generalised costs).

K2. International Evidence

Very few studies were identified that estimated the total generalised cost of private vehicle travel and even fewer studies that achieved some level of market segmentation (Table K1).

Oldfield (1974) undertook a literature review of UK evidence. He found a range of values between –0.5 and –2.6, although he did not differentiate between SR and LR values. Oldfield cited Thompson's work, which derived best estimates in the range -0.8 to –1.5, but noted that these would be on the low side as the walk time component was not included.

More recently, the UK SACTRA review (1994) estimated typical generalised time values (i.e. excluding direct costs) as in the range –0.5 to –1.0; while Gunn et al. (1998) derived a modelled estimate for Paris of –1.32 (–0.97 with respect to time components, –0.35 with respect to cost components).

In the only study to focus on differences between SR and LR values, Lee (2000, cited in VTPI 2002) estimated SR values in the range –0.5 to –1.0, with LR values in the range –1.0 to –2.0.

K3. Conclusions

In part based on the international evidence reviewed here, and in part based on assessment of the individual component elasticities, we would recommend the following set of generalised cost elasticities for use in policy assessments (Section 5.2 in main report):

- Short-run: –0.6 on marginal costs
  –1.2 on average costs (where appropriate)

- Long-run: –1.0 on marginal costs
  –2.0 on average cost (where appropriate)

Where needed, these values may be disaggregated based on the evidence set out in Table 5.1 in the main report.

Table K1: Private Transport Generalised Cost Elasticities - International Evidence

City/Country	Measure	Method	Elasticity			Comments	Source	Rank
			Short Run	Long Run	Not Specified			
Various	Generalised cost				-0.50	Combined the values of travel time, vehicle costs, toll prices, fuel, taxes and parking prices.	NHI (1995), cited in VTPI (2002)	
Various	Generalised cost		-0.5 to -1.0	-1.0 to -2.0		Total price including fuel, vehicle wear and mileage-related ownership costs, tolls, parking fees.	Lee (2000), cited in VTPI (2002)	←←
Various	Generalised cost					Author concludes that generalised cost elasticities are generally not available, but can be determined by making a couple of assumptions. For example, a reasonable assumption might be to take the petrol price elasticity of demand for car travel to be of the order of -0.2. For some users this constitutes one fifth of the total time and money generalised cost. As such, the generalised cost elasticity is -1.0. The general procedure is to adjust up elasticities by their proportion of their generalised cost.	Halcrow Fox (1993a)	←
Various	Generalised cost	Literature review of 10 different sources			-0.5 to -2.6	Author notes that some evidence showed that car travel was more elastic than bus travel, but it was not possible to recommend a single value for the elasticity from the studies examined.	Oldfield (1974)	←←
London	Generalised cost (excluding walk time)	Time Series (1952-64)			-0.8 to -1.5 -0.5 to -2.3	Arc elasticity estimates. Range from sensitivity testing. Author notes that this wide range depends on the assumptions made, with most estimates closely grouped around –1.0. Author notes that despite this wide range such calculations make a useful contribution to the very small amount of information which is available on the elasticity of demand for travel. This analysis did not include walk times in these generalised costs, so total elasticities would be slightly larger in absolute terms if they were to be included.	Thompson, cited in Oldfield (1974)	←←
UK	Generalised cost	Transport modelling			-2.6		Tulpule, cited in Oldfield (1974)	←
London	Generalised cost	Time Series (1954-70)			-0.8	Author notes that total generalised cost is two times the elasticity for running costs.	Goodwin, cited in Oldfield (1974)	←
Paris	Total time	Transportation modelling			-0.97 -0.35	Elasticity wrt total time Elasticity wrt total cost	Gunn et al. (1998)	←
Boston	Travel time				-0.82 -1.02	Work trips Shopping trips	Domenich (1969), cited in Transtech Management Inc. & Hagler Bailly (2000)	←

Table K1: Private Transport Generalised Cost Elasticities - International Evidence

City/Country	Measure	Method	Elasticity			Comments	Source	Rank
			Short Run	Long Run	Not Specified			
Europe	Travel time	Literature review			-0.50 to -1.0		SACTRA (1994), cited in Transtech Management Inc. & Hagler Bailly (2000)	←
Various	Travel time	Literature review			Zero to -1.0		Dowling (1995), cited in Transtech Management Inc. & Hagler Bailly (2000)	
UK	Travel time	Literature review			-0.28 to -0.57		Goodwin (1996), cited in Transtech Management Inc. & Hagler Bailly (2000)	
Atlantic Countries	Travel time		-0.13 to -0.43				Fulton et al. (2000), cited in Transtech Management Inc. & Hagler Bailly (2000)	
San Francisco	Price and IVT separate effects	Mode choice modelling			-0.47 -0.22	Price IVT Work trips	McFadden (1974), cited in Gomez Ilbanez et al. (1999)	←

Appendix L: Elasticity Formulations

This Appendix L defines in more detail and compares the three different measures of elasticity commonly found in the transport literature and introduced in Section 2.2 of the main report:

- Point elasticity
- Arc elasticity
- Shrinkage ratio.

The three concepts are illustrated based on Figure L1.

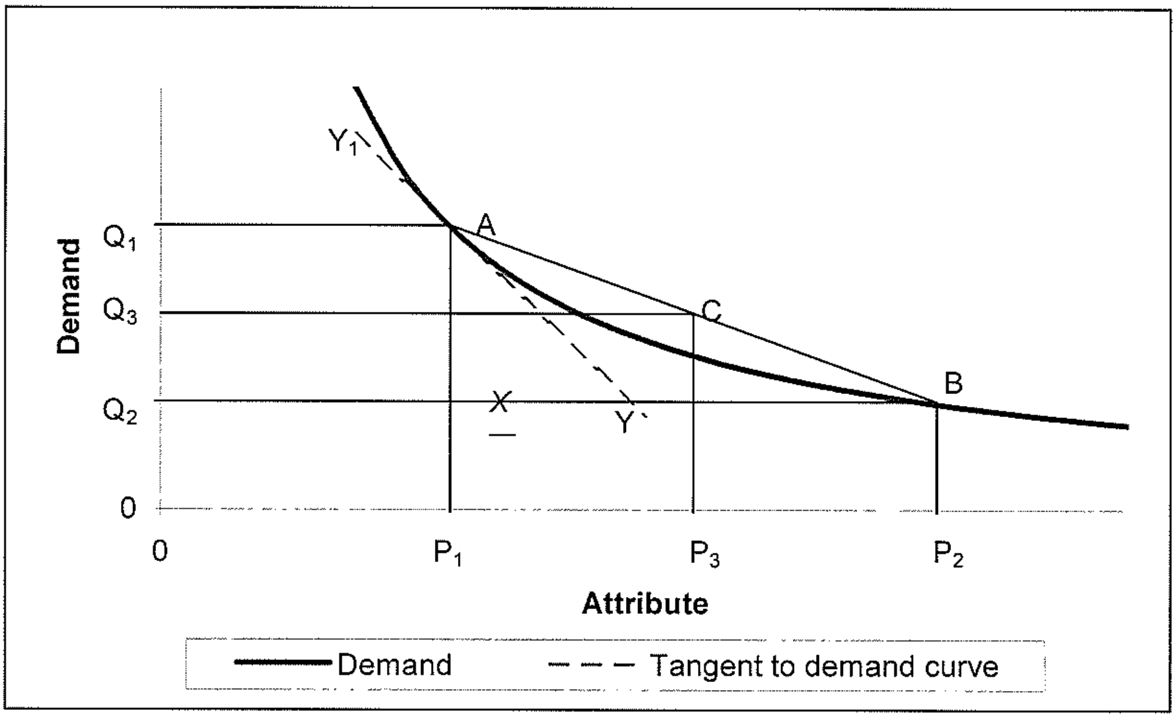

Figure L1: The three measures of elasticity: point, arc, and shrinkage ratio.

The **point elasticity** is the 'textbook' definition of elasticity. It represents the ratio of the proportionate change in the dependent variable to the proportionate change in the independent variable, for a very small change:

$$e_p=(dQ/Q)/(dP/P)= (dQ/dP).(P/Q)$$

where:

e_p is the elasticity at price *P*;

Q the quantity demanded at that price; and

(dQ/dP) represents the derivative of the quantity v price function, i.e. the slope of the demand curve (as given at point A in Figure L1 by the dashed line YY_1).

In practice, point elasticities cannot be computed from empirical data unless the shape of the demand curve is known (or postulated) and its parameters then estimated from the observed data. Therefore two other elasticity formulations are commonly applied which do not require this knowledge.

The **arc elasticity** concept is frequently employed in practical analysis. For small changes it approximates the point elasticity. One approach assumes a constant-elasticity demand function for the range of the change. The elasticity can then be estimated by:

$$e = \frac{\Delta \log Q}{\Delta \log P} = \frac{\log Q_2 - \log Q_1}{\log P_2 - \log P_1}$$

This is equivalent to: $Q_2/Q_1 = (P_2/P_1)^e$

which is consistent with the constant-elasticity demand function: $Q = k\,P^e$

An alternative approach, which gives similar (but generally not identical) results except in cases of very large changes in P and Q, uses a linear formulation based on the average value of each variable (C in Figure L1):

$$e = \frac{AX}{Q_3} \div \frac{BX}{P_3} \text{ (using the labelling of Table L1)}$$

$$e = \frac{\Delta Q}{(Q_1 + Q_2)/2} \div \frac{\Delta P}{(P_1 + P_2)/2} = \frac{\Delta Q(P_1 + P_2)}{\Delta P(Q_1 + Q_2)} = \frac{(Q_2 - Q_1)(P_1 + P_2)}{(P_2 - P_1)(Q_1 + Q_2)}$$

where:

e	is the elasticity,
Q_1 and Q_2	are the demand before and after, and
P_1 and P_2	are the price or service before and after.

In the interests of consistency, it is generally preferable to calculate arc elasticities from the logarithmic formulation.

The **shrinkage ratio** (or shrinkage factor) is a third form of elasticity often used by operators for estimating and reporting responses to public transport fare changes. In its general formulation, it is defined as the change in demand relative to the original demand divided by the change in price relative to the original price (A in Figure L1):

$$e = \frac{AX}{Q_1} \div \frac{BX}{P_1} \text{ (using the labelling of Table L1)}$$

$$e = \frac{\Delta Q / Q_1}{\Delta P / P_1} = \frac{(Q_2 - Q_1)/Q_1}{(P_2 - P_1)/P_1}$$

Shrinkage ratios are convenient for practical application by public transport operators but can cause inconsistencies in application. As an example, if the price of a service is raised and then lowered back to its original level, and the demand returns to its original level, the elasticity would logically be expected to be the same for the change in both directions, but the shrinkage ratios would differ. However, such examples rarely occur in everyday use.

Considerable confusion exists in the literature over elasticity terminology and it is unclear in many studies which definition of elasticity has been applied, without going back to the original calculations. Although shrinkage ratios are referred to in some textbooks and papers as point elasticities, the point elasticity is based on the derivative (or slope) of the demand curve at a particular point rather than the chord joining the two end-points of the change. It may be a close approximation for small changes but it is not the same thing.

The use of log or mid-point arc elasticities is becoming the preferred approach for use with quasi-experimental data. Both formulations are based on the entire portion of the demand curve under study and can be interpreted as an 'average' elasticity which is valid for any point within the range of the change. However, like all elasticity estimates, they should be used cautiously when considering major changes unless there is considerable confidence that the demand function has constant elasticity.

Figure L2 and Table L1 demonstrate that, in practice, there is little difference between these concepts for small changes but that there can be significant variations when extrapolated to large changes. Figure L2 shows three possible demand functions fitted to the same data, for values of P changing from 10 to 15 units. Each function can be found in the technical literature and generally no a priori reason is given why one should be preferred over another.

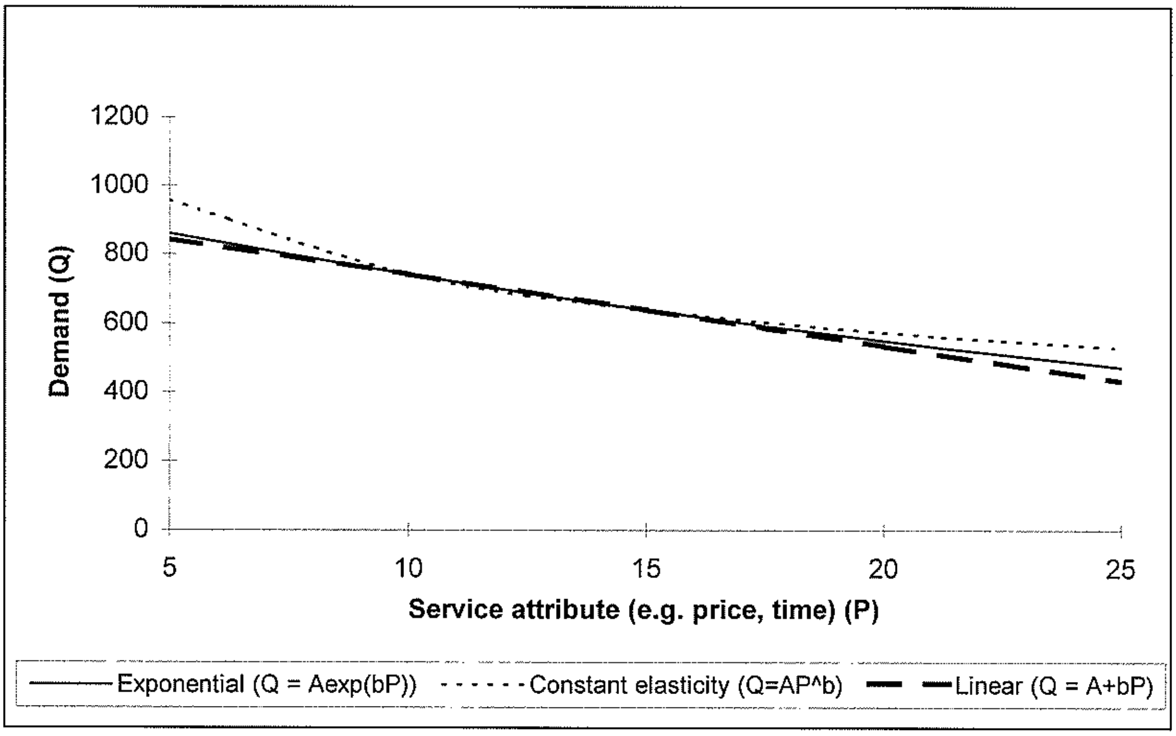

Figure L2: Alternative demand functions (see Table L1).

Table L1 shows the impact of the assumed functional form on the four different measures of elasticity, calculated mathematically from the calibrated functions:

- For the change between 10 and 15 units, the values of the two arc elasticities and the shrinkage ratio are independent of the functional form. This merely reflects the fact that these are consistent with the dataset used to calibrate the cost functions. The two forms of the arc elasticity give the same result to two decimal places but actually differ by 0.004. The point elasticity is purely a function of the point at which it is measured and thus is independent of the size of any change.
- For very small changes (say 10-11 units), there is no sensible difference between any of the measures for a particular functional form. However, the elasticity varies by up to 30% between a constant-elasticity model and the alternative proportional elasticity and linear demand models, demonstrating the assumption on functional form far outweighs definitions of elasticity in such cases.
- For larger changes (say 10-20 units), the estimates begin to diverge and, for changes outside the range of data used for estimation (based on 20 units, say), there are major differences unless the constant elasticity model is assumed.
- The shrinkage factor and point elasticity are identical for the linear demand function; the point elasticity and arc elasticity are identical (and constant) for the constant elasticity model.

The key conclusion is that all the measures can only be applied with confidence within the range of observed data, and that thought should be given as to what the underlying form of the demand function might be. It is also important that, for the larger changes, elasticities are applied in the correct manner; applying a shrinkage ratio as if it were an arc elasticity or vice versa will lead to major errors.

Table L1: Functional forms and Elasticity estimates (see Figure L2).

P_1	P_2	Q_1	Q_2	Elasticity measure Point	Arc (midpt)	Arc (log)	Shrinkage ratio
Model with elasticity proportional to P : Q = 1000exp(-.03P)							
10	11	741	719	-0.30	-0.32	-0.31	-0.30
10	15	741	638	-0.30	-0.37	-0.37	-0.28
10	20	741	549	-0.30	-0.45	-0.43	-0.26
20	22	549	517	-0.60	-0.63	-0.63	-0.58
20	30	549	407	-0.60	-0.74	-0.74	-0.52
20	40	549	301	-0.60	-0.87	-0.87	-0.45
Constant elasticity model : Q = 1736 P ^-0.37							
10	11	741	715	-0.37	-0.37	-0.37	-0.35
10	15	741	638	-0.37	-0.37	-0.37	-0.28
10	20	741	573	-0.37	-0.38	-0.37	-0.23
20	22	573	553	-0.37	-0.37	-0.37	-0.35
20	30	573	493	-0.37	-0.37	-0.37	-0.28
20	40	573	444	-0.37	-0.38	-0.37	-0.23
Linear demand model : Q = 947-21P							
10	11	741	720	-0.28	-0.30	-0.30	-0.28
10	15	741	638	-0.28	-0.37	-0.37	-0.28
10	20	741	534	-0.28	-0.49	-0.47	-0.28
20	22	534	493	-0.77	-0.84	-0.84	-0.77
20	30	534	328	-0.77	-1.20	-1.20	-0.77
20	40	534	122	-0.77	-1.89	-2.14	-0.77

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Abbreviations & Acronyms

AASHO	American Association of State Highways Officials, before 1974
AASHTO	American Association of State Highways & Transportation Officials, after 1974
ARC	Auckland Regional Council, NZ
ARRB	Australian Road Research Board
ATRF	Australasian Transport Research Forum
AUSTROADS	National Association of Road Transport & Traffic Authorities in Australia, NZ
BAH	Booz Allen Hamilton
BTE	Bureau of Transport Economics, Australia
CBD	Central Business District
BTCE	Bureau of Transport & Communications Economics, Australia
BTRE	Bureau of Transport & Regional Economics, Australia
CILT	Campaign to Improve London's Transport
CIT	Chartered Institute of Transport
DETR	Department of Environment, Transport & the Regions
DOT	Department of Transport UK, also US, and others
ECMT	European Conference of Ministers of Transport, Group on Transport & Environment
EECA	Energy Efficiency & Conservation Authority, NZ
FHWA	Federal Highways Administration, US
HCG	Hague Consulting Group
HETA	Highways Economics & Traffic Appraisal Division, Department of Transport, London
IC	Industry Commission
INFRAS	Consulting Group for Policy Analysis & Implementation
ITE	Institute of Transportation Engineers
LR	Long run
LTSA	Land Transport Safety Authority, NZ
LUL	London Underground Ltd
MMTB	Metropolitan Melbourne Transport Board
MR	Medium run
NSW	New South Wales
OTPP	Office of Transport Policy & Planning, South Australia
PT	Public/Passenger transport
PTRC	Planning & Transport Research & Computation International Association

REAAA	Road Engineering Association of Australasia & Asia
RTA	Road Traffic Authority, NSW
SACTRA	Standing Advisory Committee on Trunk Road Assessment, UK
SAM	PTRC Summer Annual Meeting
SDG	Steer Davies Gleave
SR	Short run
TCRP	Transit Cooperative Research Program, US
TEC	Traffic Engineering & Control
TEP	Transport Economics & Policy
TM	Travers Morgan
TNZ	Transit New Zealand
TRL	Transport Research Laboratory, Crowthorne, UK, after 1992
TRRL	Transport & Road Research Laboratory, Crowthorne, UK, before 1992
UK	United Kingdom
UMTA	Urban Mass Transportation Administration
US	United States of America
UTC	Urban Transport Council, NZ
UTSG	Universities Transport Study Group
VOC	Vehicle operating costs
VTPI	Victoria Transport Policy Institute, Victoria, Australia
WRC	Wellington Regional Council, NZ