Impacts of fuel price changes on New Zealand transport

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Land Transport New Zealand Research Report 331

ISBN 0-478-28744-5
ISSN 1177-0600

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*Kennedy, D., *Wallis, I. 2007. Impacts of fuel price changes on New Zealand transport. *Land Transport New Zealand Research Report 331*. 138pp.

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Keywords: Australia, bus services, carless days, diesel, econometric, elasticity, fuel, GDP per capita, international fuel consumption, modelling, New Zealand, petrol, price, public transport, rail services, roads, traffic, traffic analysis, traffic modelling

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The material contained in this report is the output of research and should not be construed in any way as policy adopted by Land Transport New Zealand but may be used in the formulation of future policy.

Contents

Executive summary

This report was prepared to assess evidence on the impacts of petrol price changes on petrol consumption, traffic volume and public transport patronage in New Zealand. In the light of this evidence and evidence from Australia and other countries, a set of 'best estimate' petrol price elasticities for the New Zealand context are recommended.

Project background

Transport fuel prices in New Zealand (as in other countries) have varied quite dramatically over the last five years. It seems likely that, in the future, petrol prices will increase further but will also continue to be volatile.

Good knowledge of the likely market responses to fuel price changes is important for a number of transport forecasting applications, including forecasting for:

- Government taxation revenues, including revenues hypothecated to the Land Transport Fund (and hence available for expenditure on the transport system).
- Fuel import demands, and the consequent impacts of fuel imports on related macroeconomic variables, such as the current account deficit.
- Transport demand and its associated energy demand.
- Transport emissions, including the impact of climate change policies such as a carbon charge and the impact on the New Zealand Government's financial obligations under the Kyoto Protocol.
- Traffic growth trends, for use in road investment planning and evaluation. (Current traffic forecasting practices in New Zealand are often based on a continuation of past traffic growth rates.)
- Public transport planning, particularly in regard to future peak demand levels and hence rolling stock requirements.

Therefore, this project was designed to contribute to more accurate forecasting processes by:

- improving information on the responses of motorists to petrol price changes;
- adding to the body of knowledge available for model forecasting and policy analysis.

Project objectives and scope

The overall objective of the project involved obtaining and combining recent information on petrol price elasticities from two sources:

- Impacts of petrol prices on New Zealand transport by econometric analysis of:
  - Petrol consumption (short and longer term);

  - Road traffic levels (vehicle kilometres travelled (VKT) by peak/off-peak, urban/rural);
  - Public transport patronage.
- Comparison of petrol price elasticities with international evidence, between New Zealand and other countries with a strong emphasis on Australia.

The scope of the project was limited to understanding the impacts of petrol prices although research into diesel price elasticities would also be beneficial.

Impacts of petrol prices on New Zealand transport

Impacts on petrol consumption

The impact of petrol prices on petrol consumption in New Zealand was investigated using a number of econometric models. Most of these models explicitly estimated the relationship between percentage changes in petrol prices and percentage changes in petrol consumption.

The preferred econometric model had several favourable features:

- The coefficients for petrol prices and GDP (Gross Domestic Product) per capita all had the expected signs.
- The coefficients for petrol prices and GDP per capita were statistically significant.
- The coefficients for petrol prices followed a plausible pattern, in that the initial impact was -0.15, falling to -0.05 the next year, and then about zero thereafter.
- No evidence of multicolinearity was seen among explanatory variables.
- The time-trend was insignificant and very close to zero.
- The model residuals exhibited desirable features, including stationarity.

The preferred model implies that a 10% (real) rise in the price of petrol will affect petrol consumption as follows:

- Petrol consumption will decrease by 1.5% within a year;
- Petrol consumption will decrease by 2% after two years;

i.e. Short Run (SR) elasticity = -0.15 and Medium Run (MR) elasticity = -0.20.

Further modelling indicated that the short-run elasticity (the impact of prices on petrol consumption over the first year) is expected to be constant over time. This elasticity showed no indication of increasing or decreasing with time.

Impacts on highway traffic volumes

The impact of petrol prices on state highway traffic volumes for cars (<5.5 m length) was also investigated, using a model that related percentage changes in petrol prices to percentage changes in traffic volumes.

Again, the preferred econometric models had several favourable features:

- The coefficients for petrol prices and GDP per capita all had the expected signs.
- The coefficients for petrol prices were statistically significant (although GDP per capita was not, apparently because of the short five-year time period which the traffic count data covered).
- The coefficients for petrol prices followed a plausible pattern, in that the initial impact was -0.22, falling to -0.08 the next year.
- No evidence of multicolinearity was seen among explanatory variables.
- The model residuals exhibited desirable features, including stationarity.

The urban traffic models imply the following impacts of a 10% (real) rise in petrol prices:

- on urban off-peak traffic, would be relatively large and most of this impact would feed through immediately in that traffic would fall by 2.7% within a year, and by 3.6% after two years (i.e. SR = -0.27, MR = -0.36);
- on urban peak traffic, would be smaller and would feed through in a more prolonged manner in that traffic would fall by only 0.9% within a year, and by 2.4% after two years (i.e. SR = -0.09, MR = -0.24);
- on rural traffic, would be more subdued, and rural traffic would fall by 1.6% within a year and by 1.9% after two years (i.e. SR = -0.16, MR = -0.19).

Impacts on public transport patronage

Models for these impacts related percentage changes in petrol consumption to percentage changes in public transport patronage (for Wellington bus and rail and Christchurch bus). Unfortunately, the models were unable to produce reliable results due to noise in the data and a number of missing variables.

Best estimates for petrol consumption and traffic volume elasticities

Drawing on all the results presented in this report, for future policy analysis purposes we suggest the following elasticity values as most appropriate for New Zealand:

- Fuel consumption elasticities:
  Overall: short-run -0.15, long-run -0.30.
- VKT elasticities:
  Overall: short-run (<1 year) -0.12, long-run (5+ years) -0.24.

These estimates are based particularly on our study results plus previous New Zealand (and Australian) studies, but also attempt to reflect the prevailing international relationships between VKT and consumption elasticities, and between long-run and short-run estimates.

Best estimates for public transport cross-elasticities

Because studies elsewhere are not transferable, and also patronage modelling appears to be unreliable, recommendations for a specific set of values for New Zealand conditions cannot be made.

The weight of evidence (from this and other studies) indicates that:

- Typical New Zealand values, largely based on Wellington evidence, average around 0.1 to 0.2.
- The limited evidence (from New Zealand and elsewhere) is that peak cross-elasticities are in the order of 2-3 times off-peak elasticities.
- The evidence (from Australian and international sources) suggest that elasticities are significantly higher than average for longer distance urban trips, especially by rail, and lower than average for shorter-distance, largely bus, trips.

Conclusions

The findings of this research may also be of interest to policy makers interested in understanding the impacts of oil shocks, excise taxes or carbon charges.

Our New Zealand petrol consumption elasticities, based on long-term 1974-2006 data, are:

- on the high side of previous New Zealand and Australian studies,
- slightly lower than the US/Canadian estimates, and
- substantially lower than the European average (but above the UK estimates, at least in the short-run).

Our New Zealand VKT elasticities, based on recent 2002-2006 data, are:

- higher than typical Australian and international values.

These VKT elasticities appear to be inconsistent with consumption elasticities, and may only be representative of the impact of petrol prices on state highway traffic.

Our New Zealand VKT elasticity results showed differences between urban peak, urban off-peak and rural responses. All the indications are that the urban peak elasticity is lower than the urban off-peak elasticity. This result reflects the less elastic nature of the commuter market overall, which is not offset by the availability of more competitive public transport services for many of these trips.

Key findings include the following:

- Petrol prices have a discernible impact on petrol consumption. The short-run and medium-run elasticities are statistically significant.

- Petrol prices appear to have quite a rapid effect on petrol consumption. A strong impact occurs within a year of a price change, with further impacts diminishing rapidly for the following year. Further impacts become indiscernible after two years.
- The estimated short-run petrol price elasticities seem surprisingly stable throughout time.
- Petrol prices have a discernible impact on vehicle traffic, especially highway traffic. Highway traffic counts appeared to have a pronounced response to petrol prices.
- GDP per capita does not appear to have as much influence on petrol consumption as petrol prices. However, the positive coefficient suggests that continued GDP growth will increase unless negated by increasing petrol prices.
- The impacts of petrol prices on public transport patronage appear to be relatively less predictable. This may be because people do not make decisions about public transport in a predictable manner which can be 'linearly related' to petrol prices.

Applications for modelling

Applications to petrol consumption forecasting models

The 'dynamic' petrol price elasticity estimates produced by this research can be incorporated into petrol consumption forecasting models. To do this, a 1% increase in petrol price is assumed to have the following impacts on petrol consumption per capita:

- petrol consumption will fall by 0.15% within a year;
- petrol consumption will fall by a further 0.05% the next year;
- petrol consumption will fall by 0.15% over the remaining years (e.g. 0.0115% each year for 13 years).

Such petrol consumption forecasting models would have a range of applications for policy analysts/advisers who:

- may be looking at carbon charges or fuel excise charges and who want to understand the impact of such policies on petrol consumption;
- may want to explore scenarios in which petrol prices rise because of external factors (e.g. Middle East conflicts, 'peak oil' effects on oil prices);
- may want to carry out sensitivity analysis to look at the impacts of a range of different price paths for petrol prices.

The petrol consumption forecasting models could also incorporate GDP elasticity estimates, as our econometric research indicates that a 1% increase in GDP per capita increases petrol consumption per capita by 0.32%.

Applications to traffic forecasting models

Highway traffic elasticity estimates can be incorporated into traffic forecasting models. To do this, a 1% petrol price increase is assumed to have the following impacts on total highway traffic per capita for which car and van traffic will fall by:

- 0.22% within a year;
- 0.08% the next year.

Similar assumptions could be used to develop specific forecasting models for subsets of traffic (rural, urban off-peak and urban peak).

These forecasting models could be used by road controlling authorities when estimating future traffic flows (and associated travel time benefits) for roading projects.

Applications to fiscal planning

The petrol elasticities produced by this research could also be incorporated in the Treasury's fiscal planning processes, e.g. projecting New Zealand's financial obligations under the Kyoto Protocol, and understanding the revenue implications of a carbon charge or an increase in excise tax.

Implications for policy making

Implications for public transport operators and funding agencies

The preliminary econometric analysis of patronage data for public transport described in this report has identified challenges that will need to be addressed in any future econometric analysis of patronage data.

- The analysis shows that relationships between petrol prices and public transport use are not as straightforward as those shown in petrol consumption and traffic. Therefore, future analysis will need to explore:
  - a wide range of models; and
  - a wide range of interrelationships between petrol prices and patronage (e.g. very short run, short run, medium run and long run).
- The analysis shows considerable 'noise' in the data because of the omission of variables that can have a big impact on patronage growth, which make robust statistical relationships difficult to estimate. Future analysis will need to adjust for this noise and/or develop econometric methods that accommodate such influences.

Implications for climate change and energy policies

The petrol price elasticities can be incorporated in forecasting models which can be used to explore the impacts of climate change measures and energy policies such as a carbon charge. It also provides information for climate change and energy policy-makers.

- Increasing the price of petrol appears to be effective at reducing greenhouse gas emissions from the transport sector.
- Responses to such price measures would generally be quite rapid as impacts will feed through into petrol consumption within one to two years.
- Responses of petrol consumption to price changes is surprisingly stable throughout time so that price measures will always remain an effective policy tool.

- GDP per capita has a positive impact on petrol consumption.

Implications for road infrastructure investment

The traffic elasticities indicated that state highway traffic was responsive to petrol prices in that a 1% increase in petrol prices causes about a 0.3% (or more) reduction in car and van traffic. This could have implications for road controlling authorities' assessments of road projects given the possibility of rising petrol prices in the future.

Increased petrol prices may have a stronger impact on state highway traffic than on local road traffic, but more evidence would be required to confirm this.

Further research directions

The datasets assembled for our study potentially offer the opportunity for further statistical analysis beyond that reported here:

- Diesel consumption elasticities could be estimated using similar econometric methods to those already undertaken for petrol.
- Diesel vehicle traffic elasticities could be estimated using similar econometric methods. As more data are available the impact of diesel prices on both heavy vehicle traffic counts and total kilometres driven could also be estimated, as well as the impact of Road User Charges (RUCs) on traffic counts and kilometres driven:
  - Elasticities for heavy vehicle traffic on state highways could be estimated using vehicle count data from Transit NZ;
  - Elasticities for total kilometres driven could be estimated using kilometres driven data, from 1995 onwards from Land Transport NZ's RUC database.
- The petrol elasticity models used for this research assume that percentage changes in petrol consumption (and VKT) are linearly related to percentage changes in petrol prices. Some evidence, however, showed that percentage changes in petrol consumption may be linearly related to absolute changes in petrol prices. These two approaches could be compared and assessed.
- The public transport patronage models employed for this project could be re-estimated in the future using longer time series, to exploit the 'natural experiment' created by the recent rise and fall in petrol prices.
- Further research into public transport patronage models would enable development of a greater range of econometric models and approaches (e.g. cointegration and ARIMA models), and address the econometric 'noise' issues identified in this report.
- A more exploratory area of research is the impact of price expectations. Econometric methods could be developed that simulate price expectation behaviour and attempt to explain the impacts of price expectations on transport behaviour, e.g. long-run behavioural responses such as vehicle choice.

Abstract

The impacts of petrol price changes on petrol consumption, traffic volume and public transport patronage in New Zealand are discussed. Based on this evidence and that from Australia and other countries, a set of 'best estimate' petrol price elasticities for the New Zealand context, of –0.15 for the short run and of –0.20 for the medium run, are recommended.

Transport fuel prices in New Zealand (as in other countries) have varied quite dramatically over the last five years. Knowledge of the likely market responses to fuel price changes is important for transport forecasting applications, such as those for:

- Government taxation revenues.
- Fuel import demands, and consequent impacts of fuel imports on related macroeconomic variables.
- Transport demand and its associated energy demand.
- Transport emissions, including the impact of climate change policies.
- Traffic growth trends, for use in road investment planning and evaluation.
- Public transport planning, particularly in regard to future peak demand levels and hence rolling stock requirements.

Applications and implications of the impacts of petrol price changes on modelling, policy making and further research are made.

1. Introduction

1.1 This report

This report was prepared to assess evidence on the impacts of petrol price changes on petrol consumption, traffic volume and public transport patronage in New Zealand (NZ); and, in the light of this evidence and evidence from Australia and other countries, to recommend a set of 'best estimate' petrol price elasticities in the New Zealand context.

The project was commissioned and funded by Land Transport New Zealand, based on a concept and approach developed by Booz Allen Hamilton (NZ) Ltd (BAH).

1.2 Project background

Transport fuel prices in New Zealand (as in other countries) have varied quite dramatically over the last five years. It seems likely that in the future petrol prices will increase further, but will also continue to be volatile.

Good knowledge of the likely market responses to fuel price changes is important for a number of transport forecasting applications, including forecasting for:

- Government taxation revenues, including revenues hypothecated to the Land Transport Fund (and hence available for expenditure on the transport system).
- Fuel import demands, and the consequent impacts of fuel imports on related macroeconomic variables, such as the current account deficit.
- Transport demand and its associated energy demand.
- Transport emissions, including the impact of climate change policies such as a carbon charge and the impact on the New Zealand Government's financial obligations under the Kyoto Protocol.
- Traffic growth trends, for use in road investment planning and evaluation. (Current traffic forecasting practices in New Zealand are often based on a continuation of past traffic growth rates.)
- Public transport planning, particularly in regard to future peak demand levels and hence rolling stock requirements.

Therefore, this project was designed to improve information on the responses of motorists to petrol price changes and, in doing so, contribute to improved forecasting processes. This project reviews and disseminates recent international (and New Zealand) evidence on petrol price elasticities.

It adds to the body of New Zealand's knowledge on petrol consumption elasticities with recent econometric analysis and new econometric modelling approaches.

As well, the project produces the first econometric estimates of traffic volume elasticities for New Zealand (to the authors' knowledge). In doing so, the project has illustrated the potential for future work in this area, using the extensive Transit NZ traffic volume database. Finally, the project identifies some areas of forecasting (e.g. deriving traffic growth trends) where incorporation of petrol price impacts may be useful.

1.3 Project objectives and scope

The overall objective of the project was to deliver a set of 'best estimate' petrol price demand elasticities for use for policy analysis purposes in New Zealand. To achieve this objective the project obtained and combined recent information on petrol price elasticities from two groups of sources:

- Econometric analysis of the impacts of petrol prices in New Zealand on the following:
  - Petrol consumption (short and longer term);
  - Road traffic levels (vehicle kilometres travelled (VKT) by peak/off-peak, urban/rural);
  - Public transport patronage.
- Comparison of petrol price elasticities between New Zealand and other countries, with a strong emphasis on Australia (referring to similarities between both countries).

The scope of the project was limited to understanding the impacts of petrol prices, as was agreed with the client, Land Transport NZ.

However, research into diesel price elasticities would also be beneficial. Estimation of diesel price elasticities could be carried out using similar approaches to those discussed in this report, and would use some data collected in the course of this research. Therefore, the impacts of diesel prices on diesel consumption, vehicle kilometres travelled (VKT), and heavy vehicle traffic could potentially be investigated in a future research project.

1.4 Report structure

The rest of this report is structured as follows:

- Chapter 2 summarises the new evidence commissioned for this report and comments on the quality of the evidence, as indicated by detailed statistical analysis of the models. The report is concerned primarily with the impacts of petrol price changes on petrol consumption (1974-2006) and on car/light van traffic volumes (2002-2006). The estimated impacts of petrol prices on public transport patronage are also discussed.
- Chapter 3 then compares the new evidence with other evidence from previous New Zealand, Australian and international studies.

- Chapter 4 draws together all the evidence and develops ‘best estimate’ elasticity values for use in New Zealand. It also highlights some unresolved issues and aspects for further research using the dataset now available.
- A number of aspects are dealt with in greater detail in the appendices (and listed on the contents page).
- One of the features of the study was the use of more advanced econometric modelling methods than are often adopted in studies of this nature. While this report does not discuss these methods in detail, Appendix C provides an overview of the methods used, for the interested reader.

1.5 Acknowledgments

The role of Land Transport New Zealand, which funded the research reported here, is acknowledged.

The contributions of the peer reviewers: Mark Walkington from the Ministry of Economic Development (MED); and Jagadish Guria and his colleagues from the Ministry of Transport (MOT), are acknowledged.

The following New Zealand government departments and agencies gave assistance in the provision of data: Ministry of Transport, Statistics NZ (SNZ) and, in particular, Transit New Zealand and the Ministry of Economic Development.

John McDermott from Victoria University (VUW) contributed historical GDP (Gross Domestic Product) data and Peter Thompson from Statistical Research Associates provided suggestions during the initial stage of the project.

2. Study analyses

2.1 Analysis methods

2.1.1 Econometric models

The new evidence commissioned for this report – estimated elasticities and cross-elasticities – was estimated using the econometric models described below, with a particular emphasis on the 'season-to-season' model type described in Models 1a and 1b.

Table 2.1 Econometric models used in this study.

Model type		Period of data	Model structure(1)	Elasticities from model v (real) petrol price
1a	Four-quarter annual differences	t=quarters	$\Delta_{4t}\ Qt = f(\Delta_{4t}\ P_t,\ \Delta_{4t}\ P_{t-4},\ \Delta_{4t}\ GDP_t)$	‣ Petrol consumption ‣ Public transport patronage
1b	52-week annual differences	w=weeks	$\Delta_{52w}\ Q_w = f(\Delta_{52w}\ P_w,\ \Delta_{52w}\ P_{w-52},\ \Delta_{52w}\ GDP_w)$	‣ Traffic volumes
2	Year-to-year annual differences	y=years	$\Delta Q_y = f(\Delta P_y,\ \Delta P_{y-1},\ \Delta GDP_y)$	‣ Petrol consumption
3	Partial adjustment model	y=years	$Q_t = f(Q_{t-1},\ P_t,\ GDP_t)$	‣ Petrol consumption

(1) Q_t = Consumption, traffic volume or patronage (all per capita), in period t, w or y (logged)
P_t = Price of petrol in period t, w or y (logged)
GDP_t = GDP per capita in period t, w or y (logged)
Δ_{xp} = Change in variable over x units of time period p (for example, Δ_{52w} = Change over 52 weeks)

As noted above, the study draws considerably from the econometric approach described in Models 1a and 1b. This econometric approach was developed by BAH during the course of the project and in this report the general approach is referred to as the *season-to-season annual differences* approach. This approach does not appear to have been used elsewhere in the literature for estimating price elasticities, although aspects of it are used elsewhere.[1]

The *season-to-season annual differences* model involves calculating the difference between variables in one quarter (t) (or week (w)) of a year and the same quarter (or week) in the preceding year. The explanatory variables are all 'differenced' in the same manner. The lag/s of differences in price levels are also added to enable estimation of long-run impacts of prices.

1 The process of calculating seasonal differences is used in some macroeconomic literature. The process of including lags of price in a year-to-year differences model does not appear common, but has been used in at least one case (Selvanathan & Selvanathan 1998).

The advantages of the *season-to-season annual differences* model include the following:

- It makes the variables stationary (i.e. oscillating around a stable level) and therefore makes a spurious regression less likely than alternative methods that use non-stationary data, such as static models and partial adjustment models. For more discussion of spurious regressions see Appendix C1.
- It addresses seasonality without requiring any assumptions about the structure of seasonality. In addition, this approach is parsimonious because it does not require seasonal dummies.
- It enables exploration (and isolation) of short-run and long-run impacts of prices on quantity demanded, by including the lag of differences in petrol prices.
- It imposes less restrictive assumptions about prices on future quantity demand. In contrast, partial adjustment models assume that the impact of prices on future consumption decline exponentially over time. Similarly, distributed lag models generally assume that the impact of prices on future consumption follows a mathematical structure of some type, such as an ‘inverted v’ shape.

The other models were used to estimate elasticities but only for petrol consumption elasticities.

In the *annual differences* model the dependent variable is the difference between petrol consumption per capita in one year and consumption per capita in the previous year. The explanatory variables (including a petrol price lag) are differenced in the same manner.

In the *partial adjustment* model the dependent variable is petrol consumption. The explanatory variables are the petrol price, GDP per capita and the petrol consumption in the previous year. This model is used to estimate three parameters:

- The short-run petrol price elasticity;
- The speed of adjustment;
- The long-run petrol price elasticity.

The long-run petrol price elasticity is calculated as a function of the short-run petrol price elasticity and the speed of adjustment.

2.1.2 Data transformations

2.1.2.1 Adjustment to real prices

The data, as originally sourced, consisted of nominal petrol price variables. The consumer price index (CPI) was used to deflate these to create real petrol prices.

The GDP data used for this research was already represented as real GDP; it did not need to be deflated.

2.1.2.2 Per capita transformations

The petrol consumption, vehicle traffic and GDP variables have all been transformed into per capita variables.

Initial models predicted the dependent variable as a function of petrol prices, GDP per capita, and population. However the impact of population could not be estimated accurately, apparently because of the low variability in population growth rates (and because the population data is modelled).

To resolve the problem described above, the dependent variables were transformed into per capita variables. This reduced the number of explanatory variables (as shown in Figure 2.1) to just petrol prices and GDP per capita and, thereby, enabled better estimation of relationships. In addition, this model structure also allows users of this research to incorporate population into forecasting by assuming that it has a one-to-one impact on fuel consumption (or vehicle traffic).

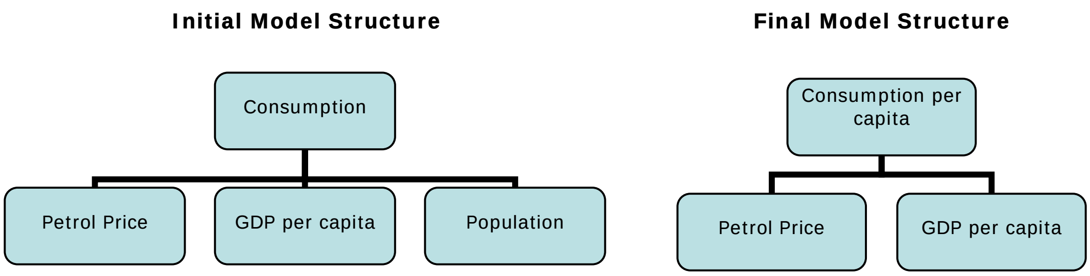


Figure 2.1 Modification of initial model structure.

Similarly, public transport patronage variables were transformed into per capita variables (using population of the area served). Again, this simplified the relationships between the remaining variables and enabled better estimation.

2.1.2.3 Natural log transformations

The variables used for this analysis were transformed using natural logs before they were included in any of the models described in Section 2.1.2.2. This enables estimation of both petrol price elasticities (contemporaneous and lagged) and a GDP elasticity, as shown in the equation below:

$$\begin{aligned} &\ln(\text{Output per Capita}_t - \text{Output per Capita}_{t-4}) = \\ &\quad \alpha + \beta \ln(\text{Petrol Price}_t - \text{Petrol Price}_{t-4}) + \gamma \ln(\text{Petrol Price}_{t-4} - \text{Petrol Price}_{t-8}) \\ &\quad + \delta \ln(\text{GDP per Capita}_t - \text{GDP per Capita}_{t-4}) \end{aligned}$$

where:

Output per Capita = Petrol Consumption per Capita, Vehicle Traffic per Capita, or Public Transport Patronage per Resident

α = *Residual Growth Rate*

β = *Contemporaneous Petrol Price Elasticity* *γ = Lagged Petrol Price Elasticity*

δ = GDP per Capita Elasticity

t = quarter

The model type is four-quarter annual differences

The model equation above can also be represented using the notation below:

$$\left(\frac{\text{Output per Capita}_{t}}{\text{Output per Capita}_{t-4}}\right) = e^{\alpha} \cdot \left(\frac{\text{Petrol Pricet}_{t}}{\text{Petrol Price}_{t-4}}\right)^{\beta} \left(\frac{\text{Petrol Price}_{t-4}}{\text{Petrol Price}_{t-8}}\right)^{\gamma} \left(\frac{\text{GDP per Capita}_{t}}{\text{GDP per Capita}_{t-4}}\right)^{\delta}$$

The models described above are often referred to as double-log (or log-log) models. Double-log models assume that constant relationships exist between proportional changes in the explanatory variables and proportional changes in the dependent variable. Therefore, this report refers to the elasticities produced using such models as *constant point elasticities.*[2]

The double-log model has been used for this research because it is commonly applied elsewhere in the transport economics literature. In addition, the double-log model assumes that the demand curve follows a convex shape, an assumption which seems plausible to the present authors, especially if one assumes diminishing returns to efforts to reduce petrol consumption.

However, as acknowledged in Section 4.7, there would be merit in investigating alternative model structures. For example, during this research, some evidence was found that elasticities might increase with price (see Section 3.1.4).

2.2 Petrol consumption analyses

2.2.1 Source data

The analyses were all undertaken at a national level. Some of the analyses used annual data covering the period 1974-2005. The remaining analyses used quarterly data covering the period March 1978–March 2006. Table 2.2 presents a summary of the data sources used.

For analysis purposes, the following variables were then used for the final modelling work:

- Petrol delivered per day per capita (dependent variable)
- Petrol price index, deflated by CPI
- GDP per capita

[2] This elasticity measure (herein referred to as a constant point elasticity) is also referred to in certain publications as an ‘arc elasticity’.

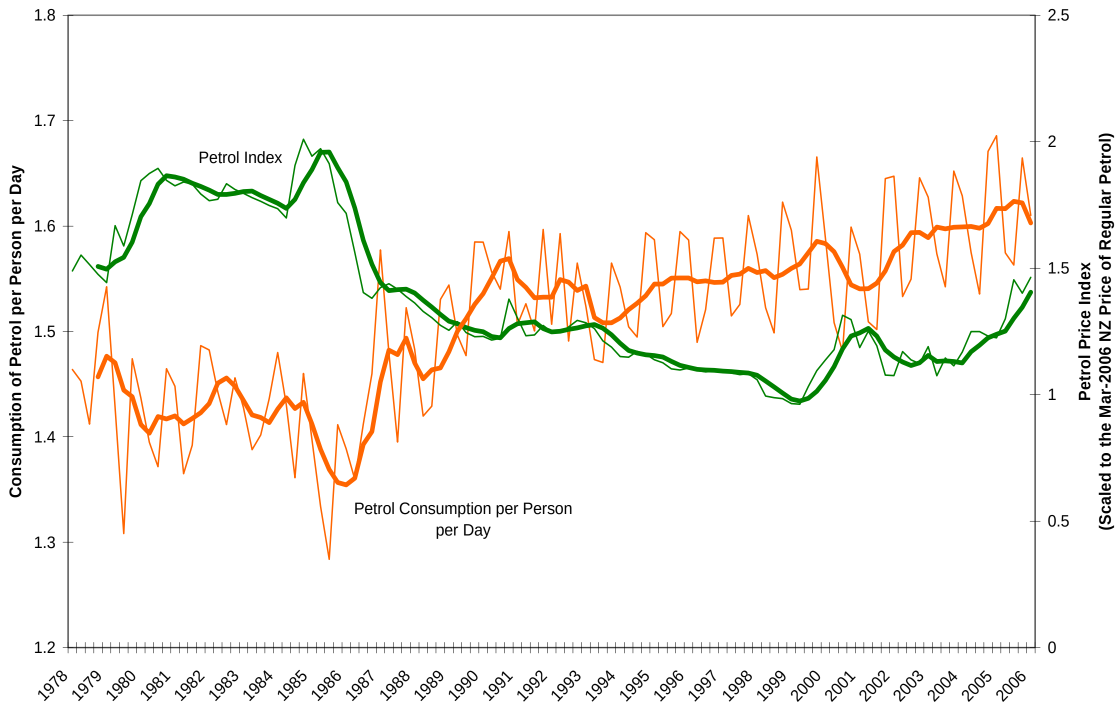
Table 2.2 Data sources for petrol consumption analyses.

Item	Source, Notes
Petrol deliveries	Tonnes of petrol delivered by oil companies (SNZ, MED).
Petrol price index	Petrol price index, representing weighted average movement of pump prices for 91 octane, 96 octane petrol and petrol additive, averaged over quarter (SNZ). The petrol price index was deflated using the CPI, to adjust for inflation.
Gross domestic product	Real GDP series with interpolation of annual data before 1977 (SNZ, VUW).
Population	Quarterly residential population estimates with interpolation of annual data before 1991.

SNZ = Statistics New Zealand,
MED = Ministry of Economic Development
VUW = Victoria University of Wellington

CPI = Consumer Price Index
GPD = Gross Domestic Product

Figure 2.2 shows changes in petrol consumption (per person per day) as the petrol price-index changed over the period 1978-2006. Both datasets have been smoothed with four-quarter-moving averages. They show that petrol consumption trends closely 'mirror' the petrol price trends.



Key: Petrol price index; petrol consumption/p/day
smoothed; fluctuations

Figure 2.2 Trends in actual petrol prices and petrol consumption (1978-2006).

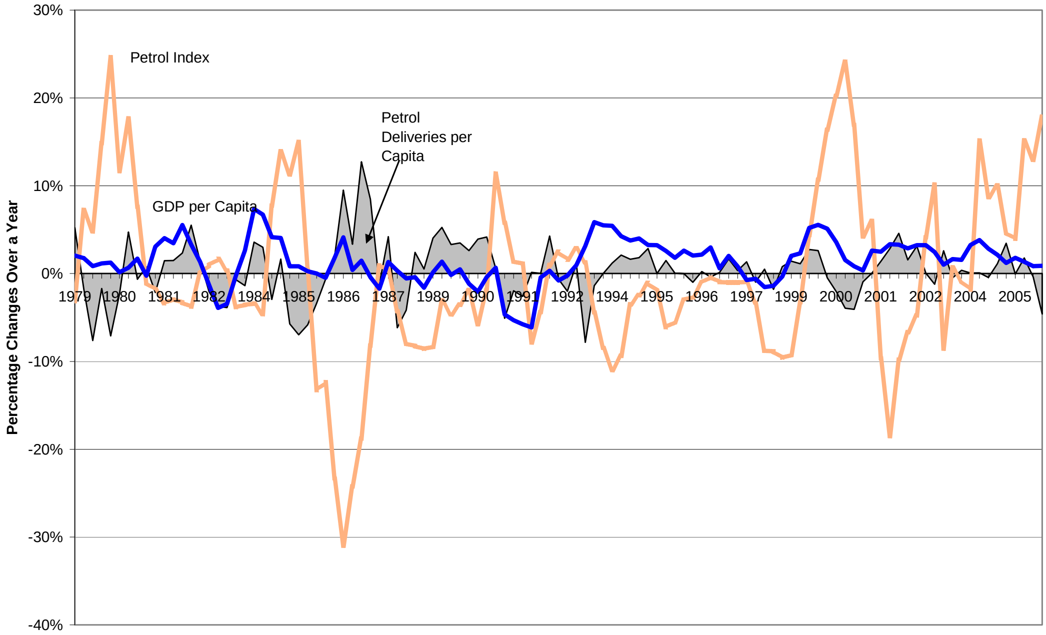


Figure 2.3 Percentage changes in petrol consumption, petrol prices and GDP per capita (1978-2006): quarterly data, year-on-year changes.

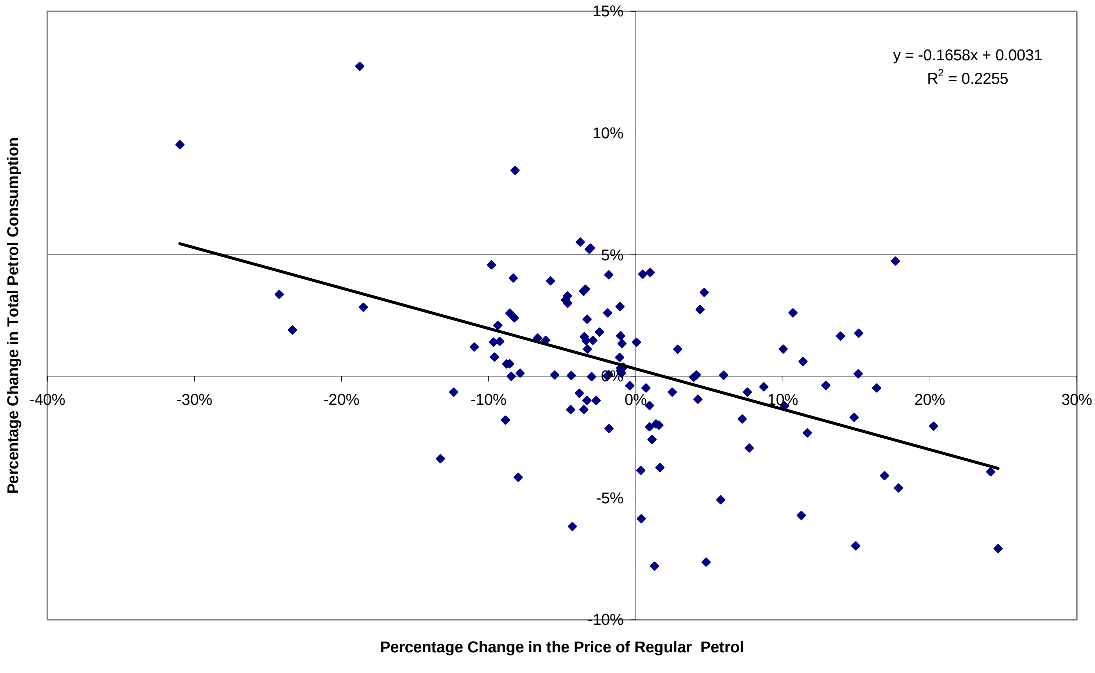


Figure 2.4 Short-run relationship between petrol prices and consumption (1978 to 2006): quarterly data, year-on-year changes.[3]

3 Note that the equation in Figure 2.4 represents the relationship between only two variables. The final model incorporated more variables.

Figure 2.3 also illustrates the relationships between petrol consumption per capita and petrol prices (with GDP per capita included as well). For each variable it shows the change in quarterly data from the corresponding data 12 months earlier. The strong relationships between consumption and price are again evident: for example, the rise in price from 1979-80 was associated with a fall in petrol consumption; similarly, the fall in price in 1986 was associated with an increase in petrol consumption. The influence of GDP per capita on petrol consumption is less clear-cut in Figure 2.3.

Figure 2.4 provides an alternative presentation of the data from Figures 2.2 and 2.3. For each quarterly period, it shows the percentage change in petrol price and petrol consumption relative to the same quarter 12 months earlier. While the results show considerable scatter, again the correlation between price changes and consumption changes is evident.

2.2.2 Models

For modelling purposes, all variables were transformed using (natural) logs, so that constant elasticity estimates could be directly derived from the model coefficients (see Section 2.1.2.3).

2.2.3 Results

Six models were estimated in this case. The results are shown below in Table 2.3 which shows the best estimates for petrol consumption price elasticity derived from each model over the following time scales:

- Within one year (‘short’ run);
- Over the second year (‘interim effect’);
- Within two years (‘medium’ run, includes short-run effects);
- After three or more years (‘long’ run, includes medium-run effects).

Model A – *the four-quarter annual differences model with GLS* (generalised least squares) – was judged to be the best model because it produces highly significant coefficients and plausible results. In addition, this is the only model in which statistical tests strongly rejected the possibility of a spurious regression (see Appendix C1 for more discussion of spurious regressions). The results of Model A are illustrated in Figure 2.5.

Model A is similar in structure to Models B, C and D. All the models regress annual changes in petrol (per capita) on annual changes in explanatory variables. However, Models B, C and D all have disadvantages:

- Model B exhibited autocorrelation, which undermines the accuracy of confidence intervals. This prompted development of the GLS version (i.e. Model A).
- Model C uses annual data and so has only the 31 observations over 31 years. This makes the estimates relatively less precise.
- Model D is probably less trustworthy because it uses a shorter time period (6 years and 66 observations) than Model A (28 years). Nevertheless, Model D is comforting because it provides remarkably similar results to Model A.

Table 2.3 Petrol consumption models and elasticity results.[1]

Model type	Petrol Price Elasticities				GDP per capita effect (0-1 years)
	Short-run effect (0-1 years)	Interim effect (1-2 years)	Medium-run effect (0-2 years)	Long-run effect (3+ years)	
A Four-quarter annual differences model (GLS) (1978-2006)[2]	-0.14*** (±0.07)	-0.04 (±0.07)	-0.19*** (±0.10)	As medium run	+0.32* (±0.26)
B Four-quarter annual differences model (OLS) (1978-2006)[2]	-0.17***	-0.06*	-0.23	As medium run	+0.35**
C Year-on-year annual differences model (1974-2005)[2]	-0.13*	-0.10*	-0.24	As medium run	+0.12
D 12-month annual differences model (GLS) (1999-2006)[2]	-0.15*** (±0.06)	+0.00 (±0.05)	-0.14** (±0.09)	As medium run	+0.56` (±0.62)
E Quarterly differences model (1978-2006)[2]	-0.06 (1st qtr) -0.11* (2nd qtr) -0.04 (3rd/4th qtr) -0.21	+0.01	-0.20	As medium run	+0.20
F Annual partial adjustment model (1974-2005)	-0.11***	n/a	n/a	-0.17	+0.07

(1) All models were annual difference models, using generalised least squares. Significance of results denoted ***0.1%, **1%, *5%, '10% (significance levels not calculated for medium-run effects). The coefficient is shown at the top of each cell and the 95% confidence interval is shown in brackets.

(2) Models A, B and E used quarterly data obtained from the MED. Model D used monthly data obtained from the MED. These data were judged to be relatively more reliable because of the MED's experience with the energy industry. However, using the MED data gave the time series for Models C and F fewer observations. Therefore, annual data obtained from SNZ were used for Models C and F, which were originally obtained in quarterly form but were aggregated to produce annual data.

Model E was estimated because it offers useful insights into the very short-run (i.e. quarterly) impacts of petrol price changes but is disadvantaged by insignificant petrol price coefficients. So it appears less useful for understanding longer term impacts of petrol prices.

Model F was estimated because it is commonly estimated elsewhere in the transport literature and it potentially offered useful insights into long-run impacts. However, it has the following disadvantage:

- Unlike the models above, Model F does not used differenced data; therefore the variables being regressed are non-stationary (i.e. they exhibit trends of some type). As discussed in Appendix C1, some authors have suggested that this can lead to non-stationarity in the error term and hence a spurious regression.

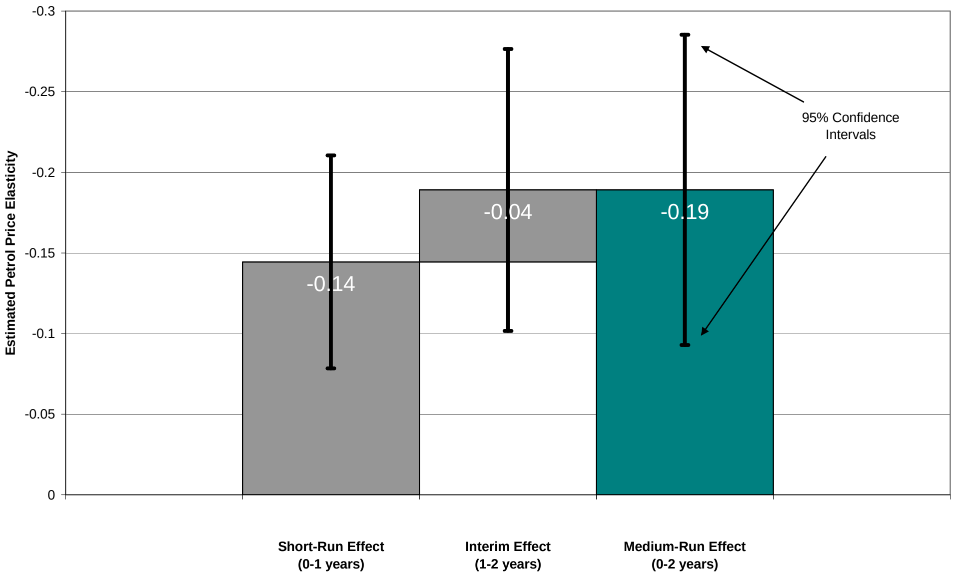


Figure 2.5 Elasticity results from the preferred petrol consumption model.

Unfortunately, the possibility of non-stationarity in the error term could not be rejected using statistical testing, as discussed in Appendix C1. In part, rejecting the hypothesis of non-stationarity is difficult given its small sample size of 30, so this model should not be discarded completely. However, by comparison, Model A seemed relatively more robust so it has been given more weight in this report.

For more detailed discussion of the merits of each model, see Appendix C2.

Despite the issues described above, it is comforting that all the models produced the following consistent themes:

- The medium-run elasticity was around -0.2.
- A large proportion (around 50% or more) of the behavioural response occurred within one year of any price change, with subsequent responses declining rapidly with time.

Short-run elasticities of petrol consumption per capita with respect to GDP per capita were also estimated from the models (as shown in the last column of Table 2.3). All the models produced positive elasticities, but the confidence intervals were a lot wider than the petrol price elasticities. In the preferred model – Model A – the elasticity with respect to GDP per capita was significant and around +0.3 (i.e. a 10% GDP per capita increase would increase petrol consumption per capita by around 3%). This impact will include both a 'car ownership effect' and an income effect.

2.2.4 Further analysis – have elasticities changed over time?

In response to questions raised by officials from interested government departments, the research project investigated whether elasticities appeared to increase or decrease over time.

Taken together, the three sources of information below suggest that the short-run elasticity seems relatively constant over time:

1. Model D (which uses the data from 1999 to 2006) produces remarkably similar estimates to Model A (which uses data from 1978 to 2006).
2. Model A was broken down into two 15-year periods (1974-89 and 1990-2006). A separate short-run petrol price elasticity was estimated for each period and the price elasticity was found to be lower in the second period; however, the difference was not statistically significant. See Appendix C2.9 in *Econometric analysis details: Consumption elasticities* for more detailed discussion.
3. Model A was modified to examine whether the short-run petrol price elasticity changed systematically with time. The modified model suggested no evidence that the elasticity grew or fell markedly with time. Again, see Appendix C2.9 in *Econometric analysis details: Consumption elasticities* for more detailed discussion.

2.2.5 Further analysis – do petrol price levels affect elasticities?

Model A was also modified to enable simple analysis of the impacts of petrol prices on the short-run elasticity. A dummy variable was used to distinguish the short-run elasticity when petrol prices were below NZ$1.50 from the short-run elasticity when petrol prices were above $1.50. Contrary to expectations, the model implied that the elasticity was higher when petrol prices were below $1.50; however, the differences were not statistically significant.

The method used to carry out this analysis was exploratory only and relatively simplistic. It is still possible that more sophisticated models could be developed that would estimate petrol price elasticities as a function of absolute petrol price levels. (Some of the international evidence indicates a tendency for higher elasticities with higher petrol prices, see Section 3.1.4, Figure 3.1.)

2.2.6 Further analysis – what was the impact of 'carless days'?

In response to a suggestion from a referee, the impact of the 'carless day' policy from February 1979 to August 1980 was incorporated in Model A as a dummy variable.
The impact of the 'carless day' policy dummy variable is shown in Table 2.4. The coefficient of this dummy variable was insignificant but retention of the dummy is perhaps justified because it increased Adjusted R^2 slightly and it changed the coefficients slightly.

2.2.7 Concluding comments

Taking into account the quality of the various models, the following findings can be drawn with respect to petrol consumption elasticities:

- A considerable degree of consistency exists across the different model results (despite reasonably wide margins of error in most cases).

Table 2.4 Petrol consumption models with and without 'carless days' dummy used for Model A.

Model type	Petrol Price Elasticities			GDP per capita effect (0-1 years)	'Carless days' policy dummy	R^2 / Adjusted R^2 (OLS version)
	Short-run effect (0-1 years)	Interim effect (1-2 years)	Medium-run effect (0-2 years)			
A Without 'carless days' dummy	-0.14*** (±0.07)	-0.04 (±0.07)	-0.19*** (±0.10)	+0.32* (±0.26)		0.31/0.30
B With 'carless days' dummy	-0.15*** (±0.07)	-0.05 (±0.07)	-0.20*** (±0.10)	+0.39** (±0.27)	-0.015 (±0.027)	0.34/0.31

Significance of results denoted as: ***0.1%, **1%, *5%, ' 10% (significance levels not calculated for medium-run effects). The coefficient is shown at the top of each cell and the 95% confidence interval is shown in brackets.

OLS = ordinary least squares.

- The short-run elasticity estimates, representing the response over a 1-year period, are around -0.15 (five of the six models give best estimates in the -0.11 to -0.17 range).
- The medium-run elasticities, representing the total response over a 2-year period, are around -0.20, with further changes beyond 2 years being very small and difficult to detect with any confidence.
- In all cases, a large proportion (around 50% or more) of the behavioural response occurred within one year of any price change, with subsequent responses declining rapidly with time.

These model estimates imply that the impacts of a 10% (real) rise in petrol prices on consumption per capita would be:

- in the short run (within 1 year), a fall of about 1.5%;
- in the medium run (within 2 years), a fall of about 2.0%.

2.3 Traffic volume analyses

2.3.1 Source data

The analyses were undertaken at a national level using weekly data, and covering the period 1 January 2002 – 18 June 2006 (4.5 years). Table 2.5 presents a summary of the data sources used.

Table 2.5 Data sources for traffic volume analyses.

Item	Source, Notes
Traffic counts	Detailed telemetry, loop and ATMS traffic count data at 108 permanent counter sites on NZ state highway network (by vehicle length, week, hour, direction), then aggregated to provide weekly peak and off-peak data (Transit NZ). Further details in text.
Petrol price	Detailed petrol prices at major Wellington service stations: daily data used to derive weekly average data (MED). The petrol price series was deflated using the CPI (interpolated) to adjust for inflation.
Gross domestic product	NZ real GDP quarterly series, interpolated to provide weekly data (SNZ).
Population	NZ quarterly residential population estimates, interpolated to provide weekly data.

ATMS = Automatic Traffic Management System

The aggregations of traffic count data on state highways throughout New Zealand were used, as a measure of total traffic volumes and as a proxy for total vehicle kilometres of travel (VKT). Traffic count data since January 2002 were available from Transit NZ at a very detailed level, by:

- Site (108 permanent counter sites);
- Hourly period of each week;
- Travel direction (on some sites);
- Four vehicle length classes. (The shortest length class, up to 5.5 metres, was taken as a proxy for petrol vehicles and has been used throughout the analysis in this report. The other three categories accounted largely for trucks which are predominantly diesel vehicles and therefore not relevant to this inquiry on petrol price effects.)

The full dataset was used to derive traffic volume summaries for each site, for the shortest vehicle length class, by week, and by peak (i.e. 0700-0900, 1600-1800 h) v off-peak periods. The results were then grouped into urban v rural areas. Total aggregated weekly traffic volumes for the shortest vehicle class were derived for the four groups: Rural, Urban Peak, Urban Off-Peak, Total All.

This process involved considerable data manipulations to adjust for situations with missing data.[4] Figures 2.6A to 2.6D (pp.30-31) show that these data manipulations were remarkably successful at 'filling in the gaps'.

4 The analyses, for this report, simply aggregated the weekly traffic volumes over all relevant sites to provide 'total traffic volumes'. It would have been possible to weight each site according to the length of road that each site could be taken to represent, and this would have provided better estimates of trends in VKT. However, this would have provided additional complexity and was not attempted. Our trend estimates are not likely to be substantially different from VKT-based trends.

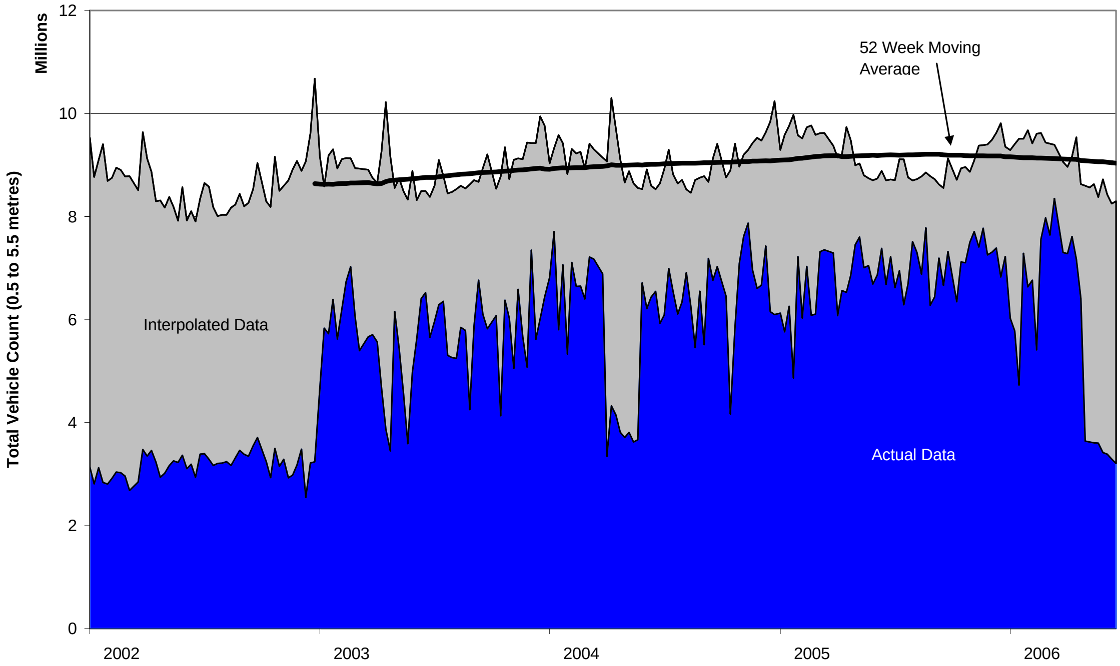


Figure 2.6A Actual and interpolated total vehicle counts (vehicles <5.5-m lengths), for 2002-2006.

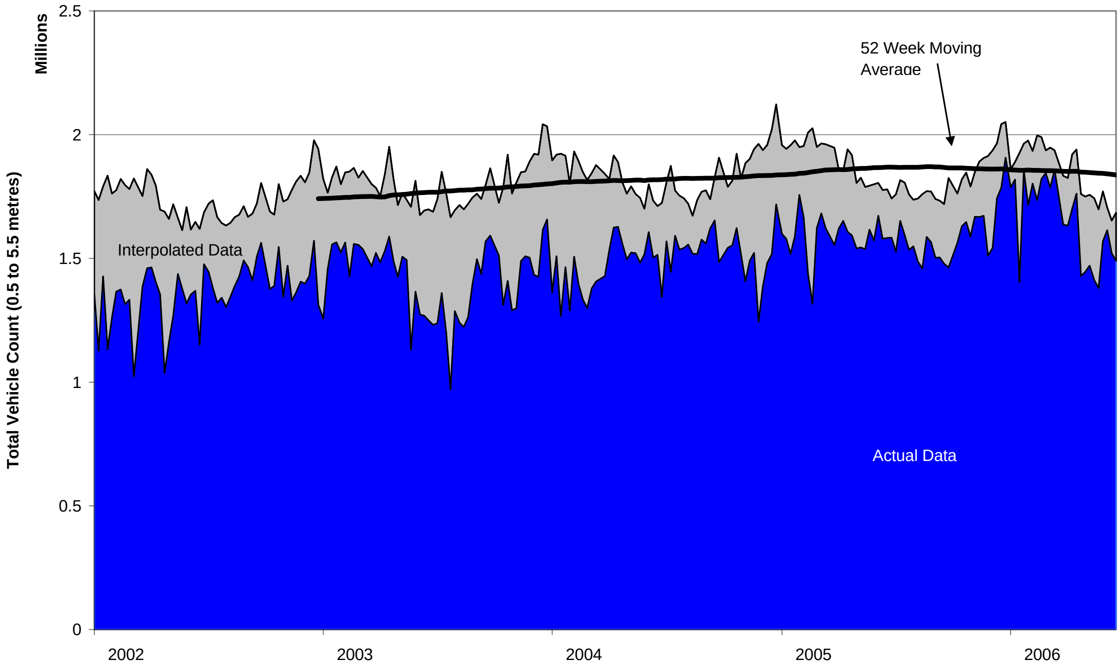


Figure 2.6B Actual and interpolated total rural vehicle counts (vehicles <5.5-m lengths), for 2002-2006.

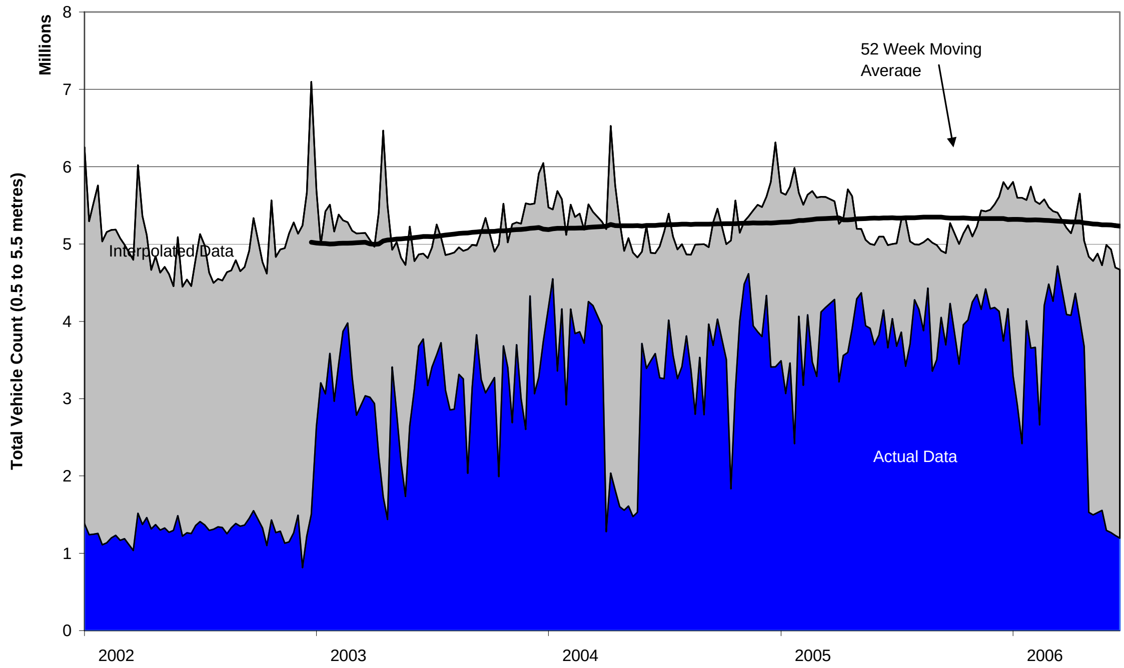


Figure 2.6C Actual and interpolated total urban off-peak vehicle counts (vehicles <5.5-m lengths), for 2002-2006.

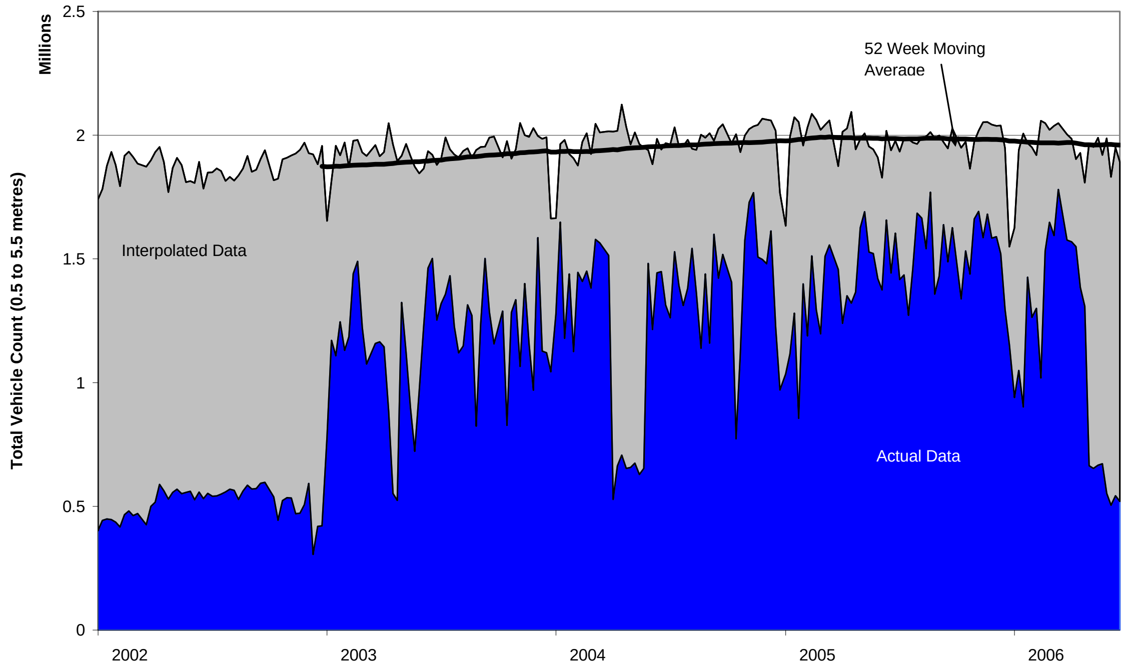


Figure 2.6D Actual and interpolated total urban peak vehicle counts (vehicles <5.5-m lengths), for 2002-2006.

For analysis purposes, the following weekly variables were used:

- Total traffic volume per week per capita (by four area/period groups) – the dependent variable;
- Average weekly petrol price, in real terms (deflated by CPI);
- GDP per capita, in real terms;

Samples of the data are shown in Figures 2.6A to 2.6D.

Figure 2.6A gives the total traffic (<5.5 metres length) volumes on a weekly basis, indicating the extent of adjustments required for missing data. To eliminate seasonality issues, it also shows the 52-week moving average volume trend: this clearly indicates a volume peak in the second half of 2005, followed by a significant decline since then.

Similar patterns are observed when the data are broken down into rural, urban off-peak and urban peak traffic counts. Note that the interpolation method seems to have worked well for rural (Figure 2.6B) and urban peak counts (Figure 2.6D). However, the interpolation method has not worked as well for urban off-peak counts (Figure 2.6C).

Using the vehicle counts data from Figure 2.6A, Figure 2.7 gives the percentage change over the previous 52 weeks (smoothed using a 13-week moving average basis) in total 'car' traffic volumes (per capita), petrol prices and GDP per capita. Throughout the period until mid-2005, car traffic volumes per capita had increased continuously, generally at a rate of around 1%-2% per year; since then, car volume trends have become negative, with the latest (mid-2006) data indicating an annual decline of 4% to 5%.

A clear correlation is shown between traffic volumes and petrol prices, in particular for the periods around July 2003, April 2005 and since October 2005. On the other hand any correlation between traffic volumes and GDP per capita is not obvious.

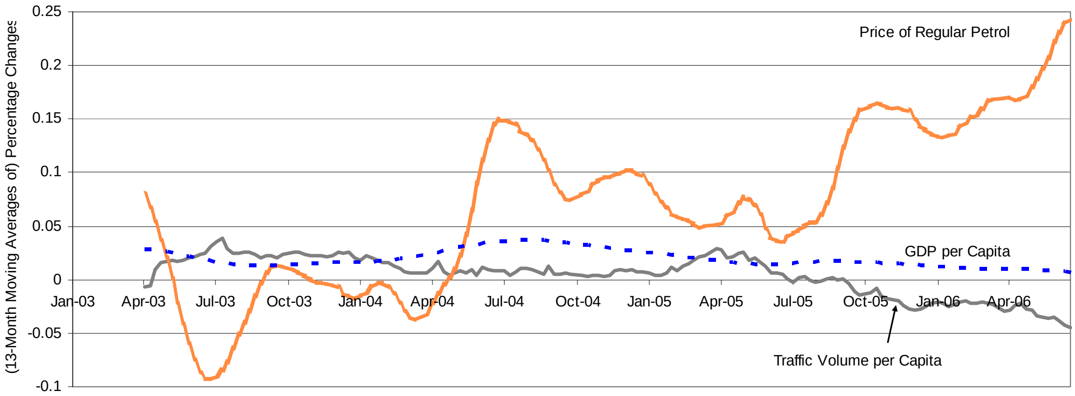


Figure 2.7 Yearly changes in total traffic volume per capita ( ), petrol price ( ) and GDP per capita ( ).

Figures 2.8A-2.8D (pp.34-35) give alternative views, using the same data, of the relationship between year-on-year changes in car traffic volumes and petrol prices.

For the four groups of traffic counts combined (Figure 2.8A), the best fit line to the data indicates an 'underlying' traffic volume growth of around 1.5-2% per annum (pa) with constant petrol prices, but changing to zero growth when petrol prices increase at around 10% pa (real terms).

Figures 2.8B (rural traffic), 2.8C (urban off-peak traffic) and 2.8D (urban peak traffic) show similar trends to Figure 2.8A (total traffic). However, the 'underlying' growth rate for the urban peak count is close to 1% pa, whereas the underlying growth rates for urban off-peak and rural traffic are closer to 2% pa.

2.3.2 Models

For modelling purposes, the three variables noted above were used, but transformed to (natural) log form (as for the petrol consumption modelling described earlier).

An annual (52-week) differences model was applied, using the change in the variable for the week in question from its value 52 weeks previously. If such a model is fitted using ordinary least squares (OLS) methods, then it produces margins of error that are inaccurate, due to autocorrelation. Therefore a generalised least squares (GLS) model was used in preference, so that margins of error could be properly estimated.

2.3.3 Results and comments

Table 2.6 shows the best estimates for car traffic volume elasticity derived for the four area/period groups, for both the 'short' run (within one year) and the 'medium' run (within two years).

Table 2.6 Car traffic volume models and elasticity results.[1]

Data Set	Petrol Price Elasticities			GDP per capita Elasticities (0-1 years)
	Short-run effect (0-1 year)	Interim effect (1-2 years)	Medium-run effect (0-2 years)	
All	-0.22*** (±0.07)	-0.08 (±0.08)	-0.30*** (±0.11)	0.14 (±0.78)
Rural	-0.16*** (±0.06)	-0.03 (±0.08)	-0.19*** (±0.11)	0.65' (±0.77)
Urban Off-Peak	-0.27*** (±0.08)	-0.09' (±0.10)	-0.36*** (±0.13)	-0.10 (±0.93)
Urban Peak	-0.10** (±0.07)	-0.18*** (±0.09)	-0.29*** (±0.12)	0.27 (±0.84)
Urban Peak – Reliable Sites[2]	-0.09*** (±0.05)	-0.15*** (±0.06)	-0.24*** (±0.08)	0.48' (±0.55)

(1) All models were annual difference models, using generalised least squares.
Significance of results denoted ***0.1%, **1%, *5%, '10%.
The coefficient is shown at the top of each cell and the 95% margin of error is shown in brackets.
The estimates all pertain to the period from January 2003 to June 2006.

(2) This dataset excludes sites that have a high proportion of missing data (this includes most of the Auckland area sites), as preliminary analysis indicated that an outlier was unduly influencing the estimates.

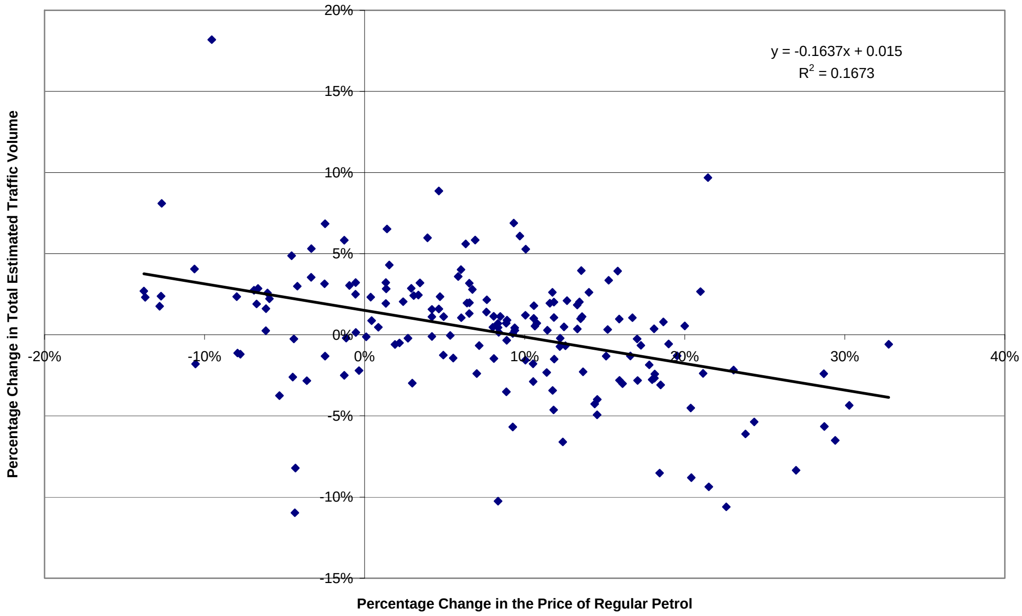


Figure 2.8A Short-run relationship between petrol prices and total traffic volumes (January 2002 to June 2006).[5]

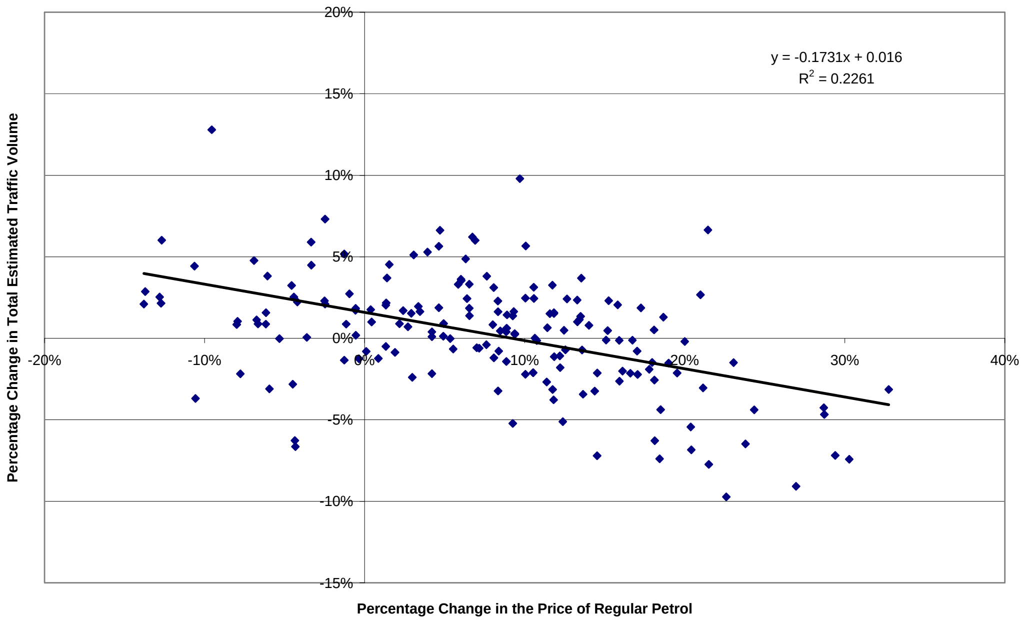


Figure 2.8B Short-run relationship between petrol prices and rural traffic volumes (January 2002 to June 2006).[5]

5 Note that the equation above only represents the relationship between two variables, whereas the final model incorporated more variables.

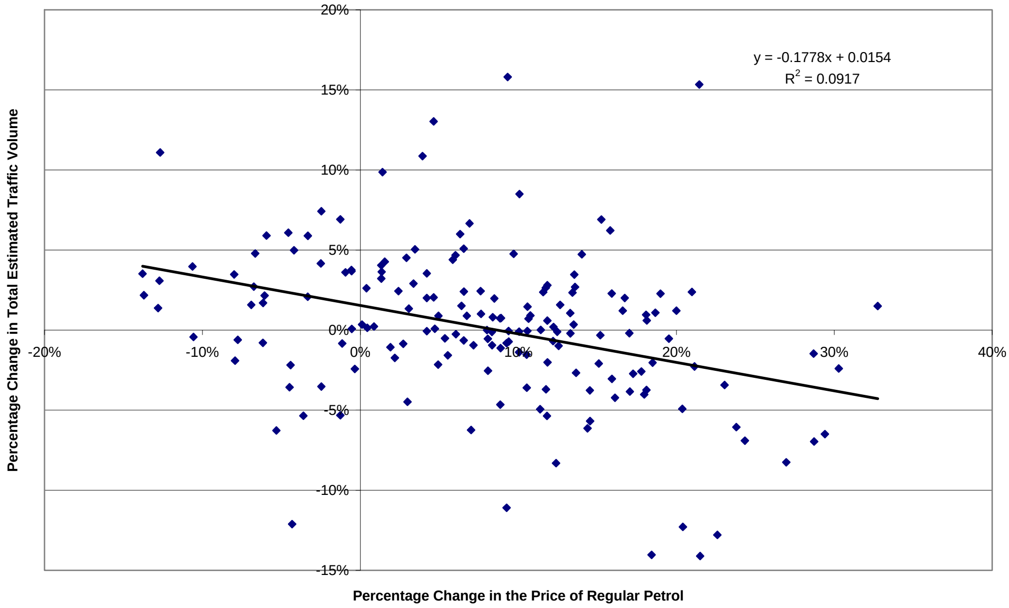


Figure 2.8C Short-run relationship between petrol prices and urban off-peak traffic volumes (January 2002 to June 2006).[5]

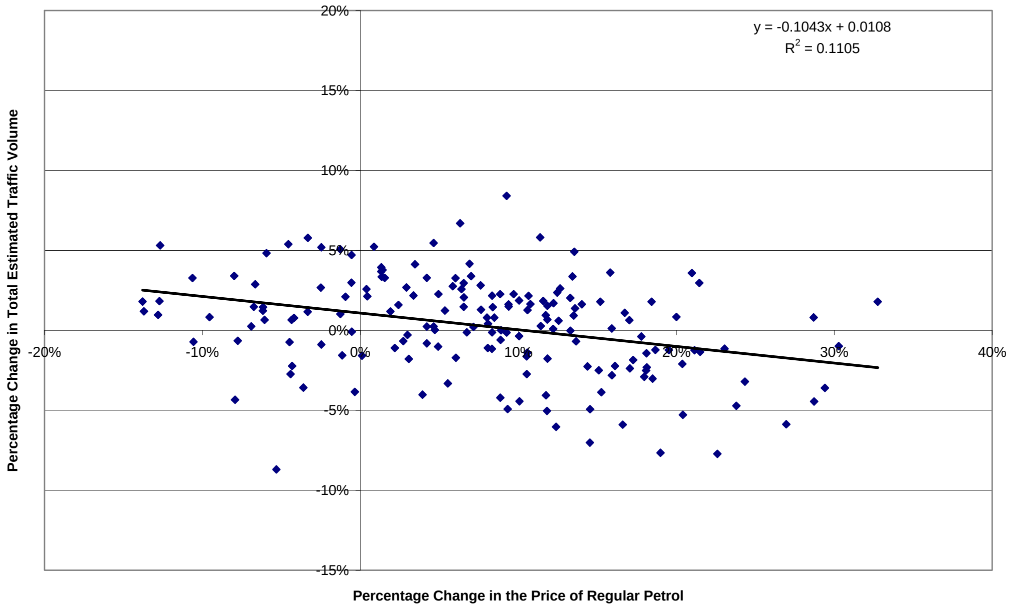


Figure 2.8D Short-run relationship between petrol prices and urban peak traffic volumes (January 2002 to June 2006).[5]

The estimates (and confidence intervals) from the respective models are also shown in Figure 2.9 below.

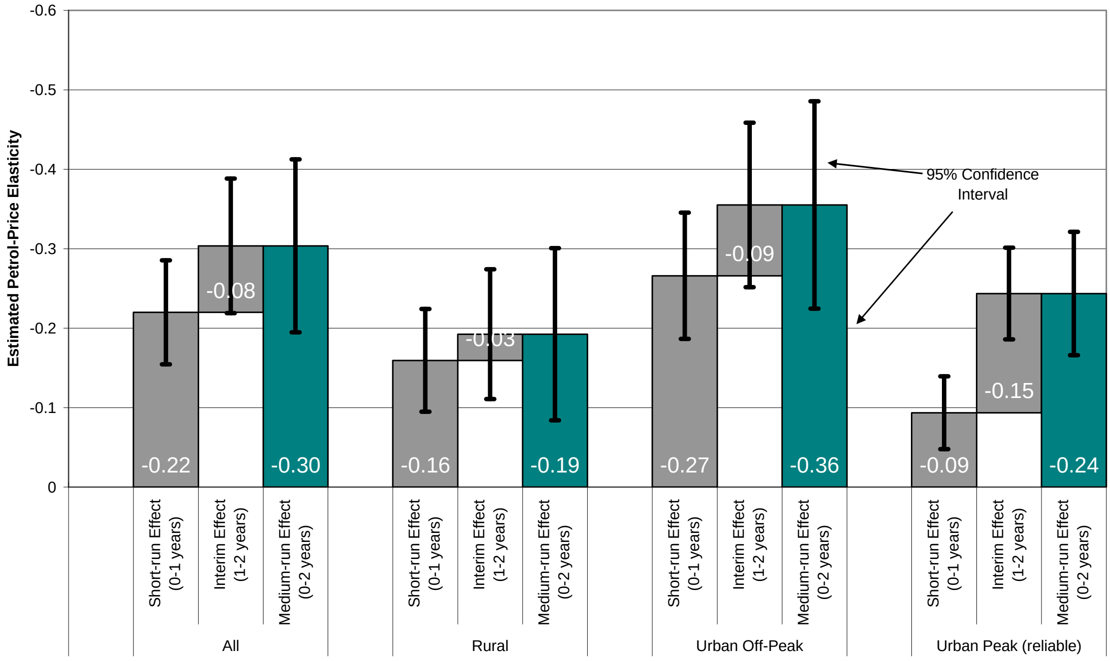


Figure 2.9 Elasticity results from the traffic volume models.

The traffic elasticities presented above should be considered with caution because they are higher than the petrol consumption elasticities. Section 3.2.4 discusses some of the reasons for this apparent inconsistency.

With that caveat in mind, inspection of the model statistical outputs indicated that the estimates for the rural and urban peak counts were likely to be more accurate than for the other groups (because they have more desirable patterns for their residuals). Having regard for this, we would draw out the following findings relating to traffic-volume elasticities:

- These elasticities follow a similar pattern to the petrol consumption elasticities discussed in Section 2.2.3, in that most of the impact occurs within the first year and any further effects decline rapidly thereafter.
- The elasticity for rural travel is relatively inelastic compared to the elasticity for all traffic.
- The elasticities for urban traffic during peak times are relatively inelastic compared to the elasticity for urban traffic during off-peak times.

The effects of changes in GDP per capita on car traffic volumes were also estimated from the models, but only two were significant, and only at 10% significance (refer Table 2.6, last column).

The estimated impacts of GDP per capita on each sub-group (rural, urban off-peak and urban peak) varied from +0.13 to +0.81 (all insignificant).

2.3.4 Concluding comments

The urban traffic model estimates imply that the impacts of a 10% (real) rise in petrol prices on urban car traffic would be as follows:

- The impact on urban off-peak traffic would be relatively large and most of this impact would feed through immediately in that traffic would fall by 2.7% within a year, and by 3.6% after two years.
- The impact on urban peak traffic would be smaller and would feed through in a more prolonged manner, in that traffic would fall by only 0.9% within a year, and by 2.4% after two years.

The rural traffic model estimates that the impacts of a 10% (real) rise in petrol prices on rural car traffic would be more subdued. Rural traffic would fall by 1.6% within a year and by 1.9% after two years.

Some limitations of the model estimates should be noted:

- The traffic count is a general class that includes all vehicle types less than 5.5 metres: i.e. cars, motorbikes, vans, and light commercial vehicles.
- The dependent variable, i.e. traffic counts, is intended to be a proxy for national VKT by car traffic, but it actually includes counts of vehicles on state highways only. The traffic count does not pick up travel on roads other than state highways, so it is likely to under-represent short-distance trips.
- The current model relates the total traffic count to a petrol price index. However, the total traffic count for vehicles less than 5.5 metres includes both petrol-powered vehicles and diesel-powered vehicles. Therefore, relating the total traffic count to a combined petrol/diesel price index may be more appropriate. However, Figure 2.10 shows minimal difference between a petrol index and combined petrol/diesel index.

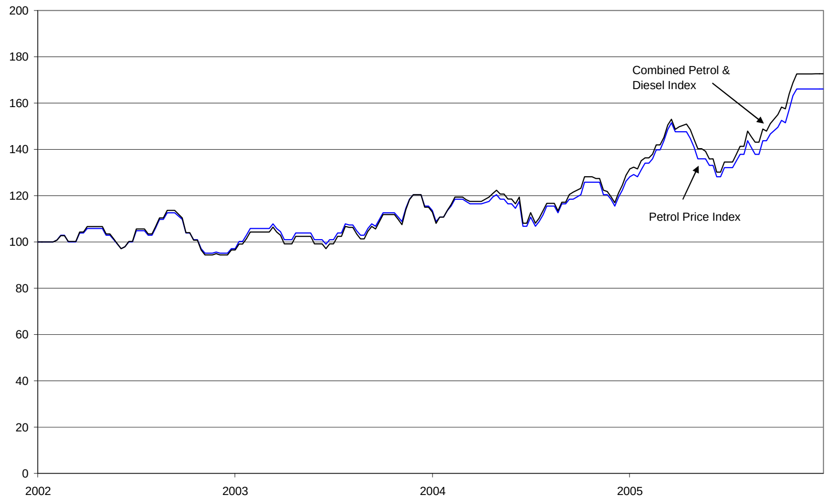


Figure 2.10 Comparison of a petrol price index with a combined petrol/diesel index.

The estimated medium-run traffic elasticities (within two years) of around -0.3 are significantly higher than the corresponding consumption elasticities of around -0.2. This apparent inconsistency is discussed in Section 3.1.4.

2.4 Public transport analyses

2.4.1 Source data for Wellington and Christchurch bus services

Analyses of public transport were undertaken for the Wellington and Christchurch areas, using quarterly time series data. Table 2.7 presents a summary of the data sources used and the time periods covered.

Table 2.7 Data sources for the public transport analyses.

Item	Wellington Bus Data Sources	Christchurch Data Sources
Period	Quarterly March 1997 – June 2006	Quarterly September 1992 – June 2006
Public transport patronage	Stagecoach bus patronage, all Wellington City routes	Environment Canterbury patronage, all Christchurch area routes
City population	Annual Wellington City population estimates (from SNZ), forecast for June 2006 and interpolated to provide a quarterly series	Annual Christchurch City population estimates, forecast for June 2006 and interpolated to provide a quarterly series
Petrol Price Index	Quarterly index for 91 octane petrol, 96 octane petrol and petrol additive (from SNZ). Petrol price index deflated using the CPI, to adjust for inflation.	
Consumer Price Index	NZ CPI quarterly series (from SNZ)	
Gross domestic product	NZ real GDP quarterly series (from SNZ), forecast for June 2006	
National population	NZ Quarterly residential population estimates (from SNZ), forecast for June 2006	

For analysis purposes, the following variables were then used (for the final modelling work):

- Patronage per day per resident population (dependent variable);
- Petrol price index, deflated by CPI;
- GDP per capita.

The patronage figures were transformed into 'per day, per resident' form to control for population growth in the areas of interest (Wellington, Christchurch). Real fare was also estimated and incorporated into the analysis, but the econometric method used (four-quarter differences) was found to be not very effective at picking up the effects of a one-off change in fares around March 2000.

2.4.2 Models for Wellington and Christchurch bus services

For modelling purposes, the three variables noted above were used, but transformed to (natural) log form.

An annual (four-quarter) differences model was applied, using the change in the variable for the quarter in question from its value four quarters previously. As in previous analyses, a GLS model was used in preference to an OLS model, so that margins of error could be more accurately estimated.

2.4.3 Results for Wellington and Christchurch bus services

The results of the Wellington and Christchurch patronage analyses are shown in Table 2.8.

Table 2.8 Public transport cross-elasticity results for Wellington and Christchurch bus patronage.(1)

Data Set	Short-run effect (0-1 years)	Interim effect (1-2 years)	Interim effect (2-3 years)	Interim effect (3-4 years)	Medium- to Long-run effect (0-4 years)	GDP effect (0-1 years)
Quarterly Wellington Stagecoach bus patronage(2)	0.16*** (±0.05)	0.21** (±0.06)	0.18*** (±0.04)	0.07** (±0.19)	0.61*** (±0.20)	0.23 (±0.45)
Quarterly Christchurch bus patronage(3)	-0.00 (±0.12)	0.13` (±0.13)	0.13* (±0.13)	n/a: insignificant	0.26 (4) (±0.40)	0.89* (±0.76)

(1) The model is a four-quarter annual difference model, using GLS, with an AR(4) error term assumed.

Significance of results denoted ***0.1%, **1%, *5%, ‘10%.

The coefficient is shown at the top of each cell and the 95% confidence interval is shown in brackets.

(2) The estimates pertain to the period March 2000 to June 2006.

(3) The estimates pertain to the period September 1994 to June 2006.

(4) The estimates for Christchurch bus patronage actually correspond to 0-3 years, rather than the 0-4 years noted above.

The Wellington bus patronage analysis, if taken at face value, implies a high cross-elasticity and a strong lagged impact of petrol prices on patronage. The Christchurch bus patronage estimates are insignificant and, therefore, inconclusive.

2.4.4 Comments – Wellington and Christchurch bus services

The results of the Wellington and Christchurch bus patronage analyses should be regarded with considerable caution:

- The residuals of the Wellington bus patronage model were unsatisfactory. There was evidence of negative autocorrelation, non-normality and non-constant variance in residuals (as noted in Appendix C4). The variance of residuals is non-constant because it increases with time; this will cause the estimated margins of error to underestimate the genuine margin of error.

- The Christchurch bus patronage model appeared to suffer from unexplained ‘noise’ in the data; a number of substantial changes have been made to bus services in the Christchurch area, and these changes could not be readily accounted for.
- Both the Christchurch bus patronage model and the Wellington bus patronage model may have been affected by the omission of important variables. For example, the creation of new routes in Christchurch may have had an influence on patronage, but this factor had to be omitted from the analysis because data were not available.

These patronage analyses are deemed inconclusive, related both to the implausibility of the results and to doubts about the statistical validity of the model.

2.4.5 Source data and model for Wellington rail services

Some analysis was also undertaken using data provided by Toll New Zealand. Toll provided monthly peak passenger rail patronage data for Wellington region for the period July 2004 to May 2006. (Patronage data before July 2004 was affected by various service disruptions, and therefore was not collected. This was supplemented by weekly petrol price data from the MED and GDP data from Statistics NZ which was interpolated to created a monthly series.)

A twelve-month annual differences model was then fitted, in which changes in total patronage were compared to changes in petrol prices and GDP. The findings were inconclusive so a per capita model was not attempted.

2.4.6 Results and comments for Wellington rail services

The results of this analysis were inconclusive. Figure 2.11 shows the percentage change in patronage for each month compared to the same month in the preceding year, and the corresponding change in petrol price.

The figure illustrates the absence of any definitive relationship between petrol prices and patronage. However, the sample consists of only 11 observations so a statistically robust relationship would have been unlikely.

Again, as with the Wellington and Christchurch bus data, a variety of factors drive patronage trends and an inability to control for these creates ‘noise’ that makes discerning accurate cross-elasticities difficult.

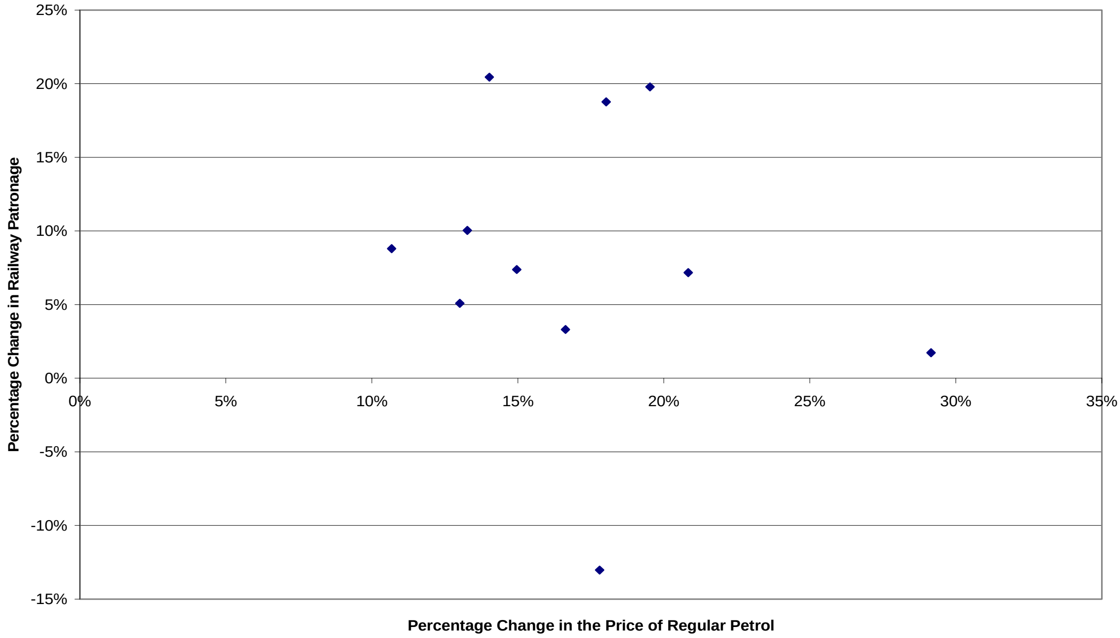


Figure 2.11 Short-run relationship between petrol prices and peak passenger rail patronage in Wellington (July 2004 to June 2006).

3. Review of earlier research

3.1 Petrol consumption elasticities

3.1.1 New Zealand evidence

Table 3.1 summarises previous econometric studies on petrol consumption elasticities in New Zealand.

Table 3.1 Previous New Zealand studies on petrol consumption elasticities.

Reference for study	Short-Run	Long-Run	Estimation Method
Barns (2002)	-0.20	-0.07	Cointegration model
MED (2000)	-0.07	-0.19	Partial adjustment model
Ministry of Commerce (1991)	-0.03	-0.07	Not established
Waikato University (1982)	-0.13	-0.16	Not established
Hughes (1980)	-0.11	-0.14	Not established

- Most short-run values are around -0.10 (range -0.03 to -0.13), and long-run values are around -0.15 (range -0.07 to -0.19).
- The exception is in Barns (2002), who estimated a relatively high short-run elasticity (-0.20) but a lower long-run figure. While her research methods appear robust, her relative long-run v short-run findings are contrary to almost all other evidence internationally.

Note that the estimates derived in our study (around -0.15 in the short run and -0.20 in the medium run) are at the high end of the range found from these previous New Zealand studies.

3.1.2 Australian evidence

Table 3.2 summarises econometric studies of petrol consumption elasticities in Australia.

- One of the most robust and transparent studies is that by Sterner et al. (1992). They fitted a partial adjustment model to Australian data from 1960 to 1985 and employed valid tests for autocorrelation. They also fitted a number of alternative models which all produced long-run estimates in the -0.1 to -0.2 range.
- These long-run estimates are supported by research by Samimi (1995), who estimated a long-run elasticity of -0.13 from data for the period 1980-1993. (Samimi's research covered both petrol and diesel, so the petrol price elasticity would be expected to be rather larger than this estimate.)
- Sterner et al.'s short-run estimate is supported by Harding's survey (2001). His elasticity estimate of -0.05 is based on household consumption only, and may underestimate the total impact, but is still more robust than many time-series estimates.

Table 3.2 Previous Australian studies on petrol consumption elasticities.

Reference to study	Short-run	Long-run	Not stated or Not established	Estimation Model / Method[6]
Brain & Schuyers (1981)	-0.11	-0.22		Not established
Donnelly (1984)	-0.12	-0.67		Not established
Filmer & Mannion (1979)	-0.03	-0.07		Not established
Harding (2001)	-0.05	n/a		Survey Analysis
Hensher & Young (1991)			-0.25 (direct estimate) -0.66 (indirect calculations)	Static Model
Samimi (1995)[7]	-0.02	-0.13		Cointegration Model
Schou & Johnson (1979)			-0.02 to -0.08	Static Models: OLS and Cooley-Prescott
Sterner, Dahl & Franzen (1992)	-0.05	-0.18		Partial Adjustment Model but other models also fitted

- The long-run values centre around -0.15 (four of five values are in the -0.07 to -0.22 range); this is again very similar to the range for New Zealand (the exception is Donnelly's estimate of -0.67), but substantially lower than the conclusion in Luk & Hepburn's (1993) review.

From this evidence, nothing indicates any significant differences between Australian and New Zealand consumption elasticities.

3.1.3 International evidence

Sterner et al. (1992) produced estimates of short-run and long-run elasticities for 21 OECD countries. These estimates are useful for comparisons across countries because they were produced using the same model (a partial adjustment model) and with data covering the same period (1960-1985). Their estimates aggregated by countries or regions of particular interest are summarised in Table 3.3.

Table 3.3 International studies for petrol consumption elasticities.

Country / Region	Short-run	Long-run
Australia	-0.05	-0.18
US	-0.18	-1.00
Canada	-0.25	-1.07
Europe		
- average	-0.28	-0.88
- range	-0.05 to -0.57	-0.18 to -2.29
- UK	-0.11	-0.45

Source: Sterner et al. (1992).

6 The estimated method was inferred when not clearly stated: most models that produce distinct 'short-run' and 'long-run' estimates are partial adjustment models.

7 Samimi (1995) analyses both petrol and diesel consumption together so his estimates are not strictly petrol price elasticity estimates, but rather transport-fuel price elasticity estimates.

Notable features of these results include:

- Australia shows the lowest elasticities of all countries analysed, in both the short run and long run (New Zealand was not included in this study).
- The US and Canadian elasticities are broadly similar to each other, and substantially higher than the Australian figures, especially in the long run.
- The European average figures are somewhat higher than the US/Canadian figures for the short run, and somewhat lower in the long run.
- The European averages encompass a considerable range across the different countries: UK is near the bottom of this range, with elasticities lying between the Australian and US levels. Hanly et al. (2002), in their review of UK studies, also found that UK consumption elasticities were relatively low, with a short-run best estimate of about 0.09 and a long-run estimate of about -0.23.

3.1.4 Comparisons and conclusions

Interpretation of the range of international results in terms of underlying differences in petrol consumption elasticities between countries is far from straightforward. The Sterner et al. (1992) data was manipulated by the authors of this present report so that comparisons of consumption elasticity estimates with petrol prices in different countries could be made. The comparisons for the short-run elasticity are summarised in Figure 3.1, which shows a relationship that is almost linear through the origin, i.e. the short-run elasticity is almost directly proportional to the price level. This implies that the percentage consumption change is more closely related to the absolute price change rather than the percentage price change. (A similar, but weaker, relationship appears to exist for the long-run elasticity estimates produced by Sterner et al.) The absolute price differences between different countries may thus explain a substantial proportion of the elasticity differences between countries.

Most analysts and commentators appear to agree that consumption elasticities are among the world's lowest in Australia and New Zealand, somewhat higher in US and Canada, and generally higher still in Europe while noting a considerable range of responses across different European countries. However, the actual differences between Australia (and New Zealand) and those in other countries may well be considerably less than the differences implied by the estimates of Sterner et al. As noted earlier, the weight of evidence indicates that Australian and New Zealand short-run values centred around -0.1, with our study estimates for New Zealand centred around -0.15, a figure which is much more comparable with the US and UK estimates, although still well below the European average. A large factor behind the higher European figures may well be the higher absolute price of petrol in these countries. Other factors could be expected to relate to the higher population densities and the greater availability and quality of alternative transport modes in Europe relative to both Australian/NZ and the US/Canadian situations. However these are merely hypotheses rather than conclusions at this stage, and do not appear to explain the apparently lower elasticities in Australia and New Zealand relative to US/Canada. This appears to be a field warranting further study.

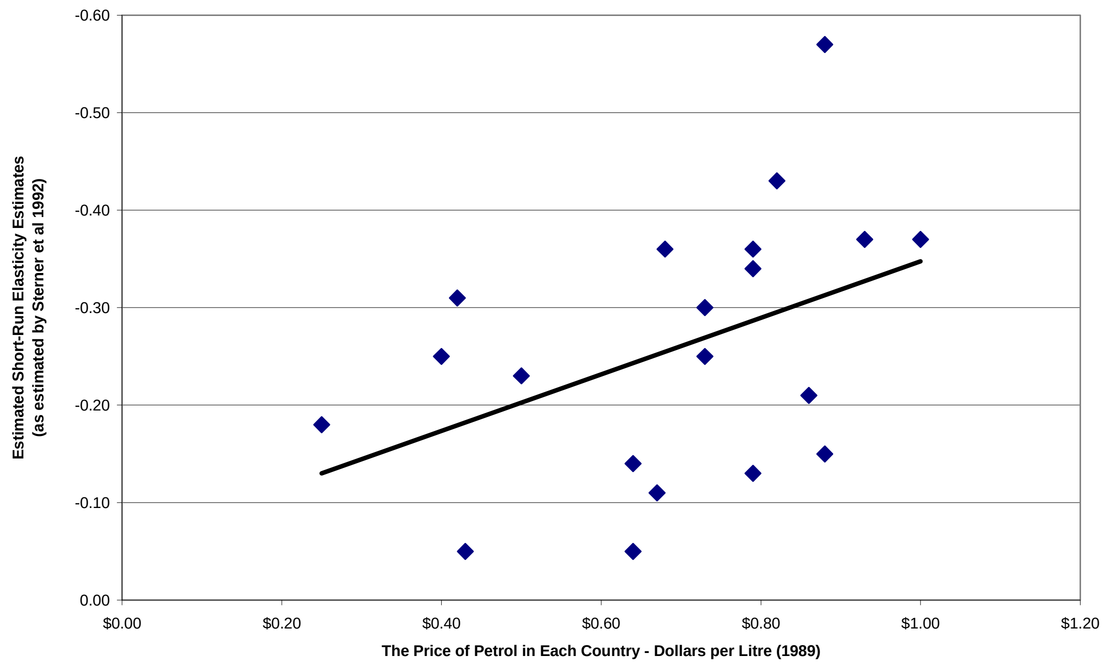


Figure 3.1 Relationship of short-run petrol consumption elasticity and price across different countries (Source: Sterner et al. 1992).

3.2 Traffic volume elasticities

3.2.1 New Zealand evidence

This appears to be the first study in New Zealand to attempt estimates of traffic volume elasticities with respect to petrol prices, and no previous studies have been identified. However, the absence of previous studies into traffic volume elasticities reflects the lack of data available in earlier times.

3.2.2 Australian evidence

Relevant Australian evidence on traffic volume (or VKT) elasticities also appears to be very limited, and we have not been able to identify any studies more recent than Luk & Hepburn's (1993) review. This review relied largely on the work of Hensher and colleagues in the early 1980s, work which collected data from a four-wave panel of Sydney area households from 1981 onwards. Luk & Hepburn's conclusions were that VKT elasticities were around -0.10 in the short-run and -0.26 in the long-run. However, to the extent that these were derived from a sample of Sydney households, we would caution to what extent they would be representative of Australia overall.

3.2.3 International evidence

A reasonably significant body of international evidence on traffic volume (VKT) price elasticities exists, although this is not as substantial as that for consumption elasticities. Table 3.4 summarises this evidence, as drawn from major review studies over the last 15 years. The mean elasticity values given here are remarkably consistent, being around

-0.15 in the short-run and around -0.30 in the long-run. Unfortunately, without an extensive in-depth appraisal. it is not possible to assess the quality of the original studies making up these mean values, nor to examine differences between countries.

Table 3.4 International studies on vehicle kilometre elasticities.[1]

Source	Short-run	Long-run	Notes, Comments
Goodwin (1992)	-0.16	-0.33	Major international review: values quoted are mean estimates.
TRACE (1998) / de Jong & Gunn (2000)	-0.16	-0.26	Review of over 50 European studies from the period 1985-1997: values quoted are mean estimates. Short-run values relate to mode choice change only (might be expected to underestimate total market responses); long-run values allow for full range of behavioural responses.
Graham & Glaister (2002, 2004)	-0.15	-0.31	Major international review: value quotes are mean estimates.
Goodwin et al. (2004)	-0.10	-0.29	Major international review, focusing on studies undertaken in the period 1992-2002, mainly in Europe and US. Results relate to mean of dynamic estimation studies (static estimation studies gave mean of 0.31).

(1) More complete evidence from international studies is provided in Wallis (2004).

3.2.4 Comparisons and conclusions

We would have anticipated (along with most other researchers in this field) a systematic relationship between traffic volume elasticities and petrol consumption elasticities. In the short-run, traffic volume elasticities would be expected to be somewhat lower than consumption elasticities because behavioural adaptations other than reduced mileage are possible even in the short-run, through changes in driving styles and speed, use of smaller cars in multi-car households etc. In the longer run, further adaptations would be expected in terms of changes in vehicle size and energy efficiency. Thus long-run traffic volume elasticities would be expected to be substantially lower than consumption elasticities.

These expected relationships appear to be present in the international data. Comparing the results from Tables 3.3 and 3.4, the typical short-run VKT elasticity for US, Canada and Europe (around -0.15) is somewhat below the consumption elasticity (around –0.24); whereas the long-run VKT elasticities (around -0.30) are markedly lower than the corresponding averaged consumption elasticities (around -1.00). Goodwin's reviews of 1992 and 2004 gave a broadly similar pattern of results.

Luk & Hepburn's 1993 review of Australian elasticity evidence also produced similar results (although this may have been a lucky outcome given the few and disparate data sources used). Their best estimates of VKT elasticities (based heavily on Sydney data) were -0.10 in the short-run, -0.26 in the long-run; while their best estimates of consumption elasticities were -0.12 and -0.50.

Perhaps unfortunately, the results from our New Zealand work do not exhibit this pattern. In the short-run (within 1 year), our best estimate traffic volume elasticity (Table 2.6) is around -0.20 to -0.22, while our petrol consumption elasticity (Table 2.4) is around -0.15. Similarly, in the medium-run (up to 2 years), our traffic volume elasticity is around -0.30, while our petrol consumption elasticity is around -0.20.

The reasons behind these apparently anomalous results are, at this stage, not fully clear. We had conjectured that this inconsistency may have been due to the different time periods used for analysis. Originally, the consumption analyses covered only the period 1974-2006, while the traffic volume analyses covered the much shorter period 2002-2006. However, the 12-month annual differences model using the counts from 1999-2006 also produced a short-run consumption elasticity of around -0.15.

Therefore, alternative explanations for the apparent inconsistency have been sought:

- Our traffic volume analyses cover only state highway traffic, and thus seem likely to over-represent longer distance journeys (relative to traffic movements overall). Our hypothesis is that longer distance journeys are more price-elastic than the market as a whole because petrol costs comprise a larger proportion of total travel costs for longer trips, and many such trips may be of a discretionary nature. Hence our traffic volume elasticity estimates would be higher than the total market estimates.
- The traffic count analyses cover only vehicles 0.5 to 5.5 metres length. A number of vehicles may be in the 5.5 to 11 metres range that run on petrol and yet are not as responsive to petrol prices (being primarily commercial vehicles). Therefore, our analyses overestimate the total traffic volume elasticity with respect to petrol price.

Our judgement is that the first of these two explanations is likely to be the main cause of the unexpected traffic volume elasticity results. The second explanation appears unlikely to be a major cause, as the number of petrol vehicles over 5.5 metres length is very small relative to the number of petrol vehicles under 5.5 metres. Further investigation of this issue by analysing count data for local roads may be worthwhile, if a consistent time series of such data for a number of sites could be obtained.

3.3 Public transport cross-elasticities

Comparisons of public transport cross-elasticity values in different situations should be used with considerable caution. Compared with direct elasticities, cross-elasticities are generally more difficult to measure; are sensitive to the ‘base’ market shares of the two models; and are not as readily transferable between different cities and situations (Wallis 2004). Cross-elasticities tend to be higher in situations where the public transport mode share is low, as a given percentage change in car travel will represent a higher percentage change in public transport trips.

While the following sections (3.3.1-3.3.4) discuss cross-elasticity results for public transport demand with respect to fuel prices across different countries and cities, and situations, the findings should be interpreted with caution given the reservations about the transferability of results.

3.3.1 New Zealand evidence

The previous New Zealand evidence on public transport cross-elasticities with respect to petrol prices is summarised in Table 3.5.

Table 3.5 New Zealand public transport cross-elasticities with respect to petrol prices.

Source	Estimate
BAH (2001)	Wgtn Total +0.18 (±0.06) Wgtn Off-peak +0.11 (±0.06) Wgtn Peak +0.29 (±0.08) Hutt Valley +0.16 (±0.16)
Wallis & Yates (1990)	+0.07
Pringle (1979: 2 studies)	Insignificant estimates
Pringle (1979)	Auckland: +0.09
Galt & Eyre (1985)	+0.2 to +0.4

The most recent cross-price elasticities appear to have been from the Booz Allen Hamilton (2001) Wellington Fares Study. Their report found plausible estimates for Wellington bus services, largely consistent with the short-run best estimates obtained from the corresponding analysis in this project (Table 2.8).

The Wallis & Yates (1990) report is also a robust piece of research, in which both static models and differences models are fitted, and both provide the same overall estimate of the cross-elasticity. In addition, the dataset used is relatively long. The results for both these studies are perhaps best taken as indicative of the short-run (i.e. one year) impact of petrol prices on patronage.

3.3.2 Australian evidence

The literature provides a wide array of differing cross-elasticity estimates for Australia, as shown in Table 3.6.

This evidence indicates that urban rail passenger patronage (both in Sydney and Melbourne) is more responsive to petrol prices than other modes of public transport, with cross-elasticities for rail services from +0.48 to +0.80. Several characteristics of rail transport make it more amenable to mode shift, such as:

- Rail transport is generally used for longer distance trips, while bus and tram have a higher proportion of short-distance trips. Commuters who travel long distances seem more likely to shift to public transport (i.e. rail) than commuters who need to travel short distances only, as the petrol costs are much more significant on longer trips.
- Rail transport may be more appealing to car users than bus and tram; hence a shift from car to rail is more likely than a shift from car to bus or tram.

Table 3.6 Australian public transport cross-elasticities with respect to petrol prices.

Authors	Region and mode	Estimate
Madan & Groenhout (1987)	Sydney transit	+0.07
Kinnear (1980)	Australian public transport	+0.01
	Melbourne bus and tram	+0.005
Willis (1994)	Adelaide public transport	+0.35 to +0.44
Gargett (1990)	Australian public transport	Insignificant negative estimates
Gallagher (1985)	Sydney suburban rail	+0.8
Singleton (1976)	Melbourne and Preston trams	Significant negative estimates
DJA-Maunsell (1992)	Australian SP survey	+0.20
Taplin et al. (1999)	Sydney SP/RP survey	+0.17
BAH (1999)	Melbourne rail	+0.70
Currie & Phung (2006)	Melbourne heavy rail	+0.475

SP = stated preference; RP = Revealed Preference

More general public transport services (primarily bus and trams) seem to exhibit much lower cross-elasticities, generally ranging from around zero to +0.20. One exception is the Adelaide public transport (mostly bus system), for which the relatively high estimates (+0.35 to +0.44) could be attributed to a low initial mode share and/or to model specification difficulties.

Some of the variation in these estimates could be due to differences in initial mode share. For example, regions with a low initial mode share will tend to be more responsive to an increase in petrol prices.

Also, some of the variation in these estimates could be due to patronage trends in the time series data that are unique to each region and/or mode. If so, the estimates from Madan & Groenhout (1987) of +0.07 may be more reliable because their research used cross-sectional data. The stated preference (SP) work may also be more reliable. Interestingly, the two pieces of SP work (Taplin et al. 1999, DJA-Maunsell 1992) both produce similar estimates of +0.17 and +0.20.

3.3.3 International evidence

The international evidence generally suggests that the New Zealand estimates are low to average by international standards. Goodwin (1992) reviewed three studies examining cross-price elasticities: Bland (1984), Doi & Allen (1986), and Wang & Skinner (1984). He concluded that the average effect of petrol prices on public transport use is represented by an elasticity of +0.34.

Since then, other research on cross-elasticities has become available, including the estimates shown in Table 3.7. More discussion of research on cross-elasticities is provided in Wallis (2004).

Table 3.7 International public transport cross-elasticities with respect to petrol prices.

Source	Country	Short-run	Long-run	Not Stated
Doi & Allen (1986) (in Goodwin 1992)	US			+0.11
Wang & Skinner (1984) (in Goodwin 1992)	US			+0.08 to +0.80
Storchman (2001)	Germany			+0.07
Bresson et al. (2002)	France	Paris: +0.04 to +0.11 France: +0.06	Paris: +0.12 to +0.19 France: +0.09	
Rose (1986)	US	+0.11	+0.18	
de Jong & Gunn (2000); TRACE (1998)	European countries	+0.33	+0.07	
	Netherlands (system model)	+0.18	+0.16	
	Italian (system model)	+0.22	+0.22	
	Brussels (system model)	+0.38	+0.37	

The research by Rose (1986) and Bresson et al. (2002) could be hypothesised to be relatively sophisticated because they incorporate lagged dependent variables and enable estimates of both short-run and long-run effects to be made. Both these pieces of research provide estimates in a similar range.

The estimates by de Jong & Gunn (2000) represent a review of the European Commission-funded TRACE (1998) research. In their review, they compare the average estimates from European literature with the estimates from three extensive transport models.

3.3.4 Comparisons and conclusions

The previous cross-elasticity estimates in New Zealand are reasonably similar, ranging from +0.07 to +0.40.

In contrast, the cross-elasticity estimates from Australia are more variable, ranging from +0.01 to +0.8. However, the high end of this range can be attributed to rail patronage which, in New Zealand, is not as dominant.

Australia exhibits a similar range if the scope is limited to the more general patronage modes (of bus, tram); the range is then 0.0 to +0.2.

However, two potential problems with the cross-elasticity estimates discussed above are as follows:

- The cross-elasticities produced using time series data (including the new evidence provided in this report) could be affected by patronage trends in the data that are unique to each region or mode.

To some extent, this problem can be circumvented with examination of estimates produced using cross-sectional or stated preference studies: these studies suggest cross-elasticities in the +0.07 to +0.20 range.

- The cross-elasticities estimated for a particular city and mode can not be transferred to a different situation, especially if the mode shares differ considerably.

4. Conclusions, modelling applications and policy implications

4.1 What conclusions can be drawn?

Table 4.1 draws together and summarises all the evidence presented previously, providing traffic volume and petrol consumption elasticities from our New Zealand analyses, previous New Zealand analyses, Australian analyses, and international analyses. Focusing particularly on the short-run results, our findings are that:

- In terms of traffic volume elasticities, our New Zealand estimates (based on recent data, 2002-2006) are higher than typical Australian and international values. As noted in Section 3.2.4, these VKT elasticities appear to be inconsistent with consumption elasticities, and may only be representative of the impact of petrol prices on state highway traffic.
- In terms of consumption elasticities, our New Zealand estimates (based on a long-term data series, 1974-2006) are on the high side of previous New Zealand and Australian studies, slightly lower than the US/Canadian estimates, and substantially lower than the European average (but above the UK estimates, at least in the short run).

Table 4.1 Summary of elasticity evidence.

Source of results	Elasticity estimates (short-run/long-run)				Notes
	VKT/Traffic Vol.		Consumption		
	SR	LR	SR	LR	
This study	-0.20 to -0.25	-0.35	-0.15	-0.20+	Traffic figures relate to 2002-06; consumption figures relate to 1974-2006
Other NZ studies			-0.1	-0.15	
Australian studies	-0.1	-0.25	-0.1	-0.15	Some studies indicate much higher LR consumption elasticities
International studies:					
US/Canada	-0.15	-0.3	-0.2	-1.0	
UK			-0.1	-0.5	
Europe average			-0.3	-0.9	

Goodwin et al. (2004) stated in their most recent international review that:

The overall picture implied is….if the real price of fuel rises by 10% and stays at that level, the result is a dynamic process of adjustment such that the following occur:

(a) Volume of traffic will fall by roundly 1% within about a year, building up to a reduction of about 3% in the longer run (about 5 years or so).

(b) Volume of fuel consumed will fall by about 2.5% within a year, building up to a reduction of over 6% in the longer run.

Comparing our study results with this statement suggests that the New Zealand traffic volume (VKT) effects are greater than these international averaged estimates, but that the New Zealand consumption effects are rather less than these international estimates. Our New Zealand results do cast some doubt on the view, quite often expressed, that New Zealand and Australian elasticities are among the world's lowest.

One of the most interesting aspects of our New Zealand VKT elasticity results is the differences between urban peak, urban off-peak and rural responses (and we are not aware of any other such disaggregated analyses in the international literature). All indications (Table 2.6) are that the urban peak elasticity (-0.29 medium run) is substantially lower than the urban off-peak (-0.36) elasticity: this result reflects the less elastic nature of the commuter market overall, which is not offset by the availability of more competitive public transport services for many of these trips.

4.2 'Best estimates' for petrol consumption and traffic volume elasticities

Drawing on all the results presented in this report, for future policy analysis purposes we would suggest that the following elasticity values are the most appropriate for New Zealand:

- Fuel consumption elasticities:
  Overall: short-run -0.15, long-run -0.30.
- VKT elasticities:
  Overall: short-run (<1 year) -0.12, long-run (5+ years) -0.24.

These estimates are based particularly on our study results plus previous New Zealand (and Australian) studies, but attempt to reflect the prevailing international relationships between VKT and consumption elasticities, and between long-run and short-run estimates. As is evident from Table 4.1, these recommended values are similar to the prevailing estimates found in other New Zealand and Australian studies.

The justification for the fuel consumption elasticities is as follows:

- A short-run (0-1 years) elasticity of -0.15 is suggested on the following grounds:
  - This is the estimate produced by model A (adjusted for the 'carless days' policy, Section 2.2.6) which we have judged to be the preferred model based on significance of coefficients and investigation of the residuals (as discussed in Section 2.2.3 and Appendix C2.9).
  - This estimate is consistent with previous New Zealand studies (Section 3.1.1) which generally found that the short-run elasticity is in the -0.03 to -0.20 range.
- A medium-run (0-2 years) elasticity of -0.20 is recommended because a range of models fitted for this research produced around this figure after 2 years.

- A long-run elasticity of -0.30 is suggested, based on the following two arguments:
  - The international literature generally finds that long-run effect is around 2.5 times the short-run effect. For example, Goodwin et al. (2004) found that the average ratio is 2.56. Graham & Glaister (2004) found that the average ratio is 3.1. We have assumed that the long-run effect is around 2 times the short-run effect because previous New Zealand studies (see Section 3.1.1) have generally found lower ratios; also, the research undertaken for this report failed to detect significant long-run effects beyond two years.
  - A long-run elasticity higher than -0.30 would seem unreasonable given that none of the New Zealand studies found a long-run elasticity above -0.19. Similarly, most Australian studies estimated a long-run elasticity no higher than -0.22 (with the sole exception of Donnelly (1984) who used older data and an unexamined econometric method).

The vehicle traffic elasticities produced by this research appear to provide statistically robust estimates of the impacts of petrol prices on state highway (largely longer distance) vehicle traffic for cars and vans. The model used to produce the elasticities seemed statistically robust and produced plausible estimates. Furthermore, similar estimates were produced using four separate datasets.

However, the inconsistency (between the vehicle traffic elasticities and the petrol consumption elasticities) suggest that the vehicle traffic elasticities represent the impact of petrol prices on state highway VKT but not on total national VKT.

The resolution to this inconsistency, as proposed until further information is obtained, is to discount the petrol consumption elasticities produced by this research to produce estimates for total VKT elasticities:

- A short-run (0-1 years) VKT elasticity of -0.12;
- A medium-run (0-2 years) VKT elasticity of -0.15;
- A long-run VKT elasticity of -0.20.

These suggested values are acknowledged to be somewhat subjective, and are drawn from petrol consumption elasticities and hypotheses of household responses over time to petrol price changes.

The suggested short-run and medium-run values are based on the petrol consumption elasticities, which have been judged to be relatively good estimates:

- The short-run VKT elasticity of -0.12 is slightly less than the petrol consumption elasticity of -0.14, representing a presumption that the main response to petrol prices is reduced VKT by households.

- The medium-run VKT elasticity of -0.15 is less than the petrol consumption elasticity of -0.20, with a greater difference between the VKT response and the consumption response because households may respond in the medium run with more efficient driving patterns.

The suggested long-run values are based on an assumed ratio between short-run and long-run VKT elasticities of around +1.7. In addition, the difference between the VKT response and the consumption response becomes greater in the long run, consistent with the purchase of more fuel-efficient vehicles in the long run.

4.3 'Best estimates' for public transport cross-elasticities

For reasons discussed in previous sections, we would not recommend any specific set of values for public transport cross-elasticities for New Zealand conditions.

The weight of evidence (from this and other studies) indicates that:

- Typical New Zealand values, largely based on Wellington evidence, average around 0.1 to 0.2.
- The limited evidence (from New Zealand and elsewhere) is that peak cross-elasticities are in the order of 2 to 3 times off-peak elasticities.
- The evidence (from Australian and international sources) suggests that elasticities are significantly higher than average for longer distance urban trips, especially by rail, and lower than average for shorter distance, largely bus, trips.

4.4 Further conclusions

The elasticities presented in this report can potentially be incorporated into models that forecast petrol consumption or light vehicle highway traffic trends. The distinction between short-run and interim petrol-price elasticities enables estimation of the dynamic impacts of petrol price changes. The short-run elasticity (-0.15) is used to estimate the impact over the first year, and the interim elasticity (-0.05) is used to estimate the residual effect over the following year.

For example, the simple model below (Table 4.2) illustrates how the impacts of petrol prices (and other variables) on petrol consumption can be forecast using estimates from the revised Model A (with a 'carless days' dummy) in Section 2.2.6. (Note that the hypothetical example in Table 4.2 is only intended for illustrative purposes.)

Note that the 'best estimates' recommended in this report are influenced by the estimates produced by New Zealand and international research. As uncertainty surrounds these estimates, sensitivity analysis should be employed in forecasting models to take into account that uncertainty.

Table 4.2 Hypothetical example – Forecasting 2011 petrol consumption based on observed and forecast changes in explanatory variables, using 'carless days' dummy.

Change	Explanatory variables				Forecast impact on petrol consumption for 2011
	Real petrol price		Real GDP	Population	
Observed change in petrol price in 2010	+10%				
Forecasts of changes in explanatory variables in 2011		-20%	+3%	+2%	-0.05 x (+10%) + -0.15 x (-20%) + +0.39 x (+3%) + 2% = 6%
Elasticity estimates from Model A in S2.2.6	-0.15	-0.05	+0.39	+1.00	

The findings of this research may also be of interest to policy makers interested in understanding the impacts of oil shocks, excise taxes or carbon charges. Key findings include the following:

- Petrol prices have a discernible impact on petrol consumption. The short-run and medium-run elasticities are statistically significant.
- Petrol prices appear to have quite a rapid effect on petrol consumption. A strong impact occurs within a year of a price change, with further impacts diminishing rapidly for the following year. Any further impacts of petrol price changes become indiscernible after two years.
- The estimated short-run petrol price elasticities seem surprisingly stable throughout time. Both the 1978-2006 quarterly data and the 1999-2006 monthly data provided similar short-run estimates: -0.14 v -0.15. In addition, some preliminary variations on the model (see Appendix C2.9) suggested that there is no systematic tendency for the short-run petrol price elasticity to increase or decrease over time.
- Petrol prices also have a discernible impact on vehicle traffic, especially highway traffic. The highway traffic counts appeared to be particularly responsive to petrol prices.
- GDP per capita does not appear to have as much influence on petrol consumption as petrol prices (when one takes into account the low variability of GDP growth compared to petrol price volatility). However, the positive coefficient suggests that petrol consumption will continue to grow unless petrol prices are increasing.
- The impacts of petrol prices on public transport patronage appear to be relatively less predictable. This may be because people's decisions about public transport are not deterministic: people do not make decisions about public transport in a predictable manner which can be 'linearly related' to petrol prices.

4.5 Applications for modelling

4.5.1 Applications to petrol consumption forecasting models

The petrol price elasticity estimates produced by this report can be incorporated into petrol consumption forecasting models. To do this, a 1% increase in petrol price is assumed to have the following impacts on petrol consumption per capita:

- petrol consumption will fall by 0.15% within a year;
- petrol consumption will fall by a further 0.05% the next year;
- petrol consumption will fall by 0.15% over the remaining years (e.g. 0.0115% each year for 13 years).

The figures provided above illustrate the merits of the 'dynamic' petrol price elasticities produced by this report. These 'dynamic' elasticities show the manner in which petrol prices feed through into consumption, in addition to the overall effect.

Such petrol consumption forecasting models would have a range of applications for policy analysts/advisers who:

- may be looking at carbon charges or fuel excise charges, and who want to understand the impact of such policies on petrol consumption;
- may want to explore scenarios in which petrol prices rise due to external factors (e.g. Middle East conflicts, 'peak oil' effects on oil prices);
- may want to carry out sensitivity analysis to look at the impacts of a range of different price paths for petrol prices.

The petrol consumption forecasting models described above could also incorporate GDP elasticity estimates. Our econometric research indicates that a 1% increase in GDP per capita increases petrol consumption per capita by 0.32%.

4.5.2 Applications to traffic forecasting models

In a similar manner to the process described in Section 4.5.1, the highway traffic elasticity estimates presented in Table 2.6 of this report can be incorporated into traffic forecasting models. To do this, a 1% petrol price increase is assumed to have the following impacts on total highway traffic per capita:

- Car and van traffic will fall by 0.22% within a year;
- Car and van traffic will fall by 0.08% the next year.

Similar assumptions could be used to develop specific forecasting models for subsets of traffic (rural, urban off-peak and urban peak).

These forecasting models could be used by road controlling authorities when estimating future traffic flows (and associated travel time benefits) for roading projects:

- The forecasting models could be fed known or expected changes in petrol prices (e.g. anticipated carbon charges).
- The forecasting models could be used to carry out sensitivity analysis for which a range of price paths for petrol could be explored, in order to reflect uncertainties around the potential ‘peak oil’ effect.

4.5.3 Applications to fiscal planning

The petrol elasticities produced by this report could also be incorporated into the Treasury’s fiscal planning processes, e.g. projecting New Zealand’s financial obligations under the first commitment of the Kyoto Protocol, and understanding the revenue implications of a carbon charge or an increase in excise tax.

The petrol elasticities produced by this report can be used to estimate the impact of such measures on petrol consumption, and hence revenues from such revenues.

Therefore, New Zealand Treasury may wish to understand the financial implications of a range of possible price paths for petrol prices.

4.6 Implications for policy making

4.6.1 Implications for public transport operators and funding agencies

The preliminary econometric analysis of patronage data for public transport in this report has identified challenges that will need to be addressed in any future econometric analysis of patronage data:

- The analysis shows that relationships between petrol prices and public transport use are not as straightforward as those shown in petrol consumption and traffic. Therefore, future analysis will need to:
  - explore a wide range of models; and
  - explore a wide range of interrelationships between petrol prices and patronage (e.g. very short-run, short-run, medium run and long-run).
- The analysis shows considerable ‘noise’ in the data, because of the omission of variables that can have a big impact on patronage growth. This noise makes it difficult for researchers to estimate robust statistical relationships. Therefore, future analysis will need to adjust for this ‘noise’ and/or develop econometric methods that accommodate such influences.

4.6.2 Implications for climate change and energy policies

As discussed above in Section 4.5.1, *Applications to petrol consumption forecasting models*, the petrol price elasticities can be incorporated into forecasting models. These models can also be used to explore the impacts of climate change measures and energy policies, such as a carbon charge.

However, the research outputs from this report provides information of interest to climate change and energy policy-makers such as:

- Price measures that increase the price of petrol (e.g. carbon charges, emissions trading) would appear to be effective tools for reducing greenhouse gas emissions from the transport sector. All the econometric models that we estimated showed that the impact of petrol prices was statistically significant.
- The response to such price measures would generally be quite rapid. This could have implications for climate change policy:
  – About half of the impact of petrol prices will feed through into petrol consumption within a year;
  – About two thirds of the impact of petrol prices will feed through into petrol consumption within two years.
- The response of petrol consumption to petrol prices changes is surprisingly stable throughout time. Therefore, price measures will always remain an effective policy tool.
- GDP per capita has a positive impact on petrol consumption. Therefore, petrol consumption will continue to grow unless cancelled out by other drivers such as rising petrol prices.

4.6.3 Implications for road infrastructure investment

The traffic elasticities indicated that state highway traffic was responsive to petrol prices in that a 1% increase in petrol prices causes about a 0.3% (or more) reduction in car and van traffic. This could have implications for road controlling authorities' assessment of road projects given the possibility of rising petrol prices in the future.

The report also conjectures that rising petrol prices may have a stronger impact on state highway traffic than on local road traffic, but acknowledges that more evidence would be required to confirm if this is the case or not.

4.7 Further research directions

The datasets assembled for our study potentially offer the opportunity for further statistical analysis which are listed here, and are further to those analysed for this report:

- Diesel consumption elasticities could be estimated, using similar econometric methods to those already undertaken for petrol.
- Diesel vehicle traffic elasticities could also be estimated, again using similar econometric methods. However, in this case more data are available which will enable the estimation of the impact of diesel prices on both heavy vehicle traffic counts and total kilometres travelled (VKT) (and consequent comparison of the two estimates). The impact of Road User Charges (RUCs) on traffic counts and kilometres driven could also be explored. For this analysis the following steps would need to be taken:

  - Elasticities for heavy vehicle traffic on state highways could be estimated using vehicle count data collected from Transit NZ.
  - This traffic count dataset could be cleaned to adjust for missing observations.
  - This traffic count dataset divides vehicles into four length classes, but to date (2007) only the shortest length class (<5 m, largely cars and light vans) has been used to estimate VKT elasticities with respect to petrol price. Diesel-price elasticities could be derived for longer length classes (>5.5 m) (and this is another aspect for which very few elasticity estimates are available internationally).
  - Elasticities for total kilometres driven could be estimated using a detailed series of kilometres-driven data available from 1995 onwards.
- The petrol elasticity models used for this research assume that percentage changes in petrol consumption (and VKT) are linearly related to percentage changes in petrol prices. However, during this research, evidence showed that percentage changes in petrol consumption may be linearly related to absolute changes in petrol prices.
- Potentially the two approaches could be compared and assessed on a range of criteria, including statistical 'goodness of fit' tests and also their performance at forecasting.
- The public transport patronage models employed for this project could be re-estimated in the future using longer time series. In addition to providing more observations, the longer time series would allow us to exploit the 'natural experiment' created by the recent rise and fall in petrol prices. Further research would also enable development of a greater range of econometric models and approaches (potentially including cointegration models and ARIMA models) and would address the econometric 'noise' issues identified in this report.
- A more exploratory area of research concerns the impacts of price expectations. The research commissioned for this report and virtually all the international research focuses on the impacts of price changes. However, we conjecture that changes in price expectations may play a role, in addition to actual price changes. Therefore, econometric methods could be developed that simulate price expectation behaviour and attempt to explain the impacts of price expectations on transport behaviour (including long-run behavioural responses such as vehicle choice).

Appendices

A Price elasticity concepts

- A1 Price elasticity of demand
- A2 Cross-price elasticity of demand
- A3 Long-run and short-run responses

B Econometric analysis methods

C Econometric analysis details

- C1 Summary of modelling approach
- C2 Consumption elasticities
- C3 Traffic volume elasticities

D Review of previous research

- D1 Petrol consumption elasticities
- D2 Traffic volume elasticities
- D3 Public transport cross-elasticities

E References

Appendix A: Price elasticity concepts

A1 Price elasticity of demand

The *price elasticity of demand* is defined as the ratio of the percentage change of quantity demanded to the percentage change in price:

$$\frac{\text{Percentage Change in Quantity Demanded}}{\text{Percentage Change in Price}}$$

The price elasticity of demand indicates the responsiveness of quantity demanded by a change in price. For example, a price elasticity of -0.20 indicates that a 1% change in price will cause only a 0.2% decrease in quantity demanded. In contrast, a price elasticity of -2.3 indicates that a 1% change in price causes a 2.3% decrease in demand.

The price elasticity of demand is often categorised as elastic or inelastic:

- A good has *inelastic* demand if a 1% change in price causes a less than 1% change in consumption. Therefore, a rise in price causes an increase in total revenue.
- A good has *elastic* demand if a 1% change in price causes a more than 1% change in consumption. Therefore, a rise in price causes a decrease in total revenue.

A2 Cross-price elasticity of demand

The *cross-price elasticity of demand* for good A with respect to good B is defined as the ratio of the percentage change of quantity demand of good A to the percentage change in price of good B:

$$\frac{\text{Percentage change in quantity demanded of good A}}{\text{Percentage change in price of good B}}$$

The cross-price elasticity of demand indicates the responsiveness of the quantity demand (of one good) to the change in price (of another good).

In this report, the cross-price elasticity of demand is used to understand the responsiveness of public transport patronage to the change in price of petrol.

A3 Long-run and short-run responses

The price elasticity or cross elasticity of demand can represent either short-run or long-run responses.

In terms of economic theory, the length of the 'short-run' or 'long-run' relates to the extent to which consumers have responded to a price change:

- The short-run price elasticity of demand represents the impact of a price change before consumers have adjusted completely to a price change.
- The long-run price elasticity of demand represents the complete impact of a price change.

However, some econometric models (namely partial adjustment models) enable the estimation of the impact of a price change on consumption within a year: therefore, this one-year price elasticity is conveniently described as the 'short-run' price elasticity.

These models also estimate the indefinite impact of a price change, and this is consistent with a 'long-run' price elasticity described in economic theory.

Appendix B: Econometric analysis methods

Table B.1, on page 66, summarises:

- Econometric model forms commonly used in the transport literature in studies such as this present study (in which some of these models were used); and
- Other models applied in this study which are not commonly found in the transport literature.

Key to symbols:

C	consumption	LR	long run
P	petrol price	SR	short run
O	output		

Table B.1 Overview of econometric modelling methods.

Model	Structure	Disadvantages	Advantages	Comment
MODELS COMMONLY USED IN TRANSPORT LITERATURE				
Static Models	$C_t = f(P_t, O_t)$	‣ Risk of spurious regression	‣ Simple to apply	Commonly used for price elasticities in transport literature
Partial Adjustment Models	$C_t = f(C_{t-1}, P_t, O_t)$	‣ Risk of spurious regression and potential for biased estimates ‣ Impact of prices on consumption is assumed to decline exponentially	‣ Simple to apply ‣ Calculates SR and LR	Commonly used for price elasticities in transport literature
Distributed Lag Models	$C_t = f(P_t, P_{t-1}, P_{t-2}, \ldots, O_t)$	‣ Risk of spurious regression ‣ Impact of prices on consumption is assumed to follow certain structures (e.g. a polynomial structure)	‣ Incorporates price dynamics	Occasionally used for price elasticities in transport literature
Cointegration Models	LR: $C_t = f(P_t, O_t)$ SR: $EC = f(\Delta P_t, \Delta O_t)$	‣ Requires the establishment of a cointegrating relationship	‣ May provide good estimates ‣ Calculates SR and LR	Occasionally used for price elasticities in transport literature
Simple Differences Models	$\Delta C_t = f(\Delta P_{t,}, \Delta O_t)$	‣ High likelihood of over-differencing ‣ Autocorrelation generally has to be modelled ‣ Unable to detect long-run effects of prices	‣ Less risk of spurious regression	Occasionally used for price elasticities in transport literature
MODELS INTRODUCED OR DEVELOPED FOR THIS RESEARCH				
Differences Models with Lags	$\Delta C_t = f(\Delta P_t, \Delta P_{t-1}, \Delta P_{t-2}, \ldots, \Delta O_t)$	‣ High likelihood of over-differencing ‣ Autocorrelation generally has to be modelled	‣ Less risk of spurious regression ‣ Calculates impact elasticities over time	Occasionally used to calculate price elasticities in other disciplines, but none observed in transport literature (Selvanathan & Selvanathan 1998 is an example)
Season-to-season Differences Models	$\Delta C_t = f(\Delta P_{t-s}, \Delta P_{t-2s}, \Delta P_{t-3s}, \ldots, \Delta O_t)$	‣ High likelihood of over-differencing ‣ Autocorrelation generally has to be modelled	‣ Less risk of spurious regression ‣ Calculates impact elasticities over time ‣ Adjusts for seasonality ‣ Exploits all available data observations	Novel combination of the differences model with lags approach to price elasticities and the seasonal differencing techniques used in other fields, such as macroeconomics

Appendix C: Econometric analysis details

C1 Summary of modelling approach

C1.1 Issues with non-stationarity and spurious regressions

The modelling approaches adopted for this research were designed, in part, to mitigate possible risks with regressions involving non-stationary variables. In essence, a variable is non-stationary if the series has no tendency to revert to a constant mean.

Regressions involving non-stationary variables could be problematic. In a seminal econometrics paper, Granger & Newbold (1974) showed that a regression involving non-stationary variables can lead to a *spurious regression*, in which two completely unrelated variables can appear to have a precisely estimated relationship even if no such relationship exists in reality. Phillips (1986) later built on the work of Granger & Newbold, providing theoretical explanation for their findings.

As noted by Verbeek (2000), the problem is, in essence, that non-stationarity in the original variables can feed through into *non-stationarity in the error term* being modelled. If this happens then the regression could be spurious. Statistical theory does not provide much guidance about the level of faith to have in regressions involving non-stationarity error terms. The studies referred to above suggest that the estimates could be inconsistent and the statistical tests could be invalid. On the other hand, the regression may be detecting a genuine relationship (and it appears to do so in a number of studies).

C1.2 Approaches to mitigate the risk of spurious regressions

This report acknowledges that regressions involving non-stationary variables are commonly carried out. Furthermore, these regressions have been shown to often produce plausible and useful estimates.

However, in light of the uncertainty identified by the econometric literature above, we decided to use primarily differenced models.[8] Differenced models generally make the dependent variable and the explanatory variables stationary, and hence the error term being modelled is usually stationary. This solution was recommended by Granger & Newbold (1974) when they first drew attention to the risk of spurious regressions. They noted that even differencing is not guaranteed to prevent a spurious regression. Therefore, we also used an augmented Dickey-Fuller test to test for stationarity in the

[8] A number of other benefits are associated with difference models. These advantages include:

- Difference models relate changes in petrol consumption to changes in explanatory variables: this relationship corresponds intuitively to the concept of an elasticity.
- Differencing generally reduces multicollinearity.
- Lags can be explored, without assuming that the explanatory variables have a specific effect on the dependent variable.

error term. If stationarity in the error term can be established then a spurious regression is unlikely.[9]

C1.3 Other diagnostic analyses

The models were checked for normality of residuals and for constant variance throughout time. This is useful for checking the validity of the estimation method, but it is also useful as a means of checking for model mis-specification.

The models were checked for autocorrelation, using autocorrelation function (ACF) graphs and partial autocorrelation function (PACF) graphs.

C1.4 Generalised least squares

Any autocorrelation was adjusted for using generalised least squares (GLS). To do this, an error structure had to be assumed. A range of error structures were explored and the error structures chosen for modelling were selected based on effectiveness at removing autocorrelation (as indicated by ACF and PACF graphs). All the final models were fitted using either an MA(5), MA(4), MA(1) or AR(4) error structure.

C1.5 Interpretation of season-to-season annual differences modelling approach

As noted in Section 2.1.1 of the main report, the econometric modelling implemented here draws considerably on the approach we referred to as *season-to-season annual differences*. This approach is used for consumption models A, B and D, all the traffic models and all the public transport patronage models.

This modelling approach, in effect, generally assumes that the percentage change in the dependent variable (e.g. petrol consumption per capita, traffic count per capita) over a four-quarter period (or a 52-week period) is a linear function of the following:

1. The percentage change in petrol prices over that same four-quarter (or 52-week) period;
2. The percentage change in petrol prices over the preceding four-quarter (or 52-week) period;
3. The percentage change in GDP per capita over that same four-quarter (or 52-week) period;
4. Any residual influences on the change in the dependent variable: these influences are assumed to be normally distributed and independent of the other explanatory variables.

The coefficient of the first variable has been interpreted as a short-run petrol price elasticity: it shows how petrol price changes over a year relate to changes in the dependent variable over that same year.

9 In addition, this approach negated any need to use augmented Dickey-Fuller tests to check that the dependent and explanatory variables are stationary.

The coefficient of the second variable has been interpreted as an interim-run petrol price elasticity because it uses a *lagged* explanatory variable: it shows how petrol price changes over a year relate to changes in the dependent variable over the *next* year. (The coefficient of the third variable is interpreted in a similar manner.)

In this report, these two coefficients have been added together to produce a medium-run petrol price elasticity: this elasticity shows how petrol price changes over a year relate to changes in the dependent variable over both the same year and next year.

The method for calculating of the standard errors for the medium-run petrol price elasticity had to be developed during the course of the research. The variance of this new variable was calculated as a function of the variances and covariances of the two other coefficients, using standard statistical variance rules.

C1.6 Modelling issues with price changes of differing rapidity

Consider the following limitation of the model above: a gradual change in petrol prices over a whole four-quarter (or 52-week) period will be treated the same as a rapid increase in petrol prices at the end of the period. A referee pointed out that, in reality, households may react differently to a rapid increase in petrol prices: for example, the dramatic nature of the price rise may prompt them to change behaviour; alternatively, the rapidity of the price chance may cause them to dismiss the price change as being temporary.

This problem is not unique to the model structure described above, and most price elasticity models give little regard to the speed at which petrol prices change. To address this, models could be developed that take into account the variance of petrol price changes during a given period: thus if the price changes rapidly then the variance of price changes would generally be higher. Or quarterly-differences models (such as consumption model E) could be used: these models allow researchers to examine price changes over smaller intervals, and could be modified to allow large changes in petrol prices to have disproportionately larger impacts on the dependent variable. However, the authors note that the coefficients produced by consumption model E were not generally statistically significant, so this approach may not be successful.

This research has not attempted to incorporate the rapidity of price changes into the modelling approach, but the authors acknowledge that the referee has raised an interesting issue.

C1.7 Econometric software

The econometric models were all fitted using R software, which is described in R Development Core Team (2006).

C2 Consumption elasticities

C2.1 Introduction

Five types of models are discussed in the following sections:

- Four-quarter annual differences models (A, B)
- Year-on-year annual differences model (C)
- 12-month annual differences model (D)
- Quarterly differences model (E)
- Annual partial adjustment model (F)

These models are summarised and compared in Sections C2.1–C2.6. This summary section is followed by more detailed presentation and discussion of the empirical results for each model in C2.7–C2.15.

C2.2 Comparison of models

Before carrying out the analyses, model A was hypothesised to be a robust model, based on the reasons identified in Section 2.1.1 of the main report. Model F was estimated because it potentially offered insights into long-run impacts. The remaining models are judged to be less useful, but are presented here because they all produce remarkably similar estimates: about -0.14 in the short-run and about -0.20 in the medium-run:

Table C2.1 Comparison of model estimates.

Model type	Petrol Price Elasticities				GDP per capita effect (0-1 years)	R^2 / Adjusted R^2	Dataset
	Short-run effect (0-1 years)	Interim effect (1-2 years)	Medium-run effect (0-2 years)	Long-run effect (3+ years)			
A Four-quarter annual differences model (GLS) (1978-2006)	-0.14***[2] (±0.07)	-0.04 (±0.07)	-0.19*** (±0.10)	As medium run	+0.32* (±0.26)	0.31/0.30[1]	n = 101, quarterly
B Four-quarter annual differences model (OLS) (1978-2006)	-0.17***	-0.06*	-0.23	As medium run	+0.35**	0.31/0.30	n = 101, quarterly
C Year-on-year annual differences model (1974-2005)	-0.13*	-0.10*	-0.24	As medium run	+0.12	0.36/0.28	n = 31, annual
D 12-month annual differences model (GLS) (1999-2006)	-0.15*** (±0.06)	+0.00 (±0.05)	-0.14** (±0.09)	As medium run	+0.56` (±0.62)	0.33/0.29[1]	n = 66, monthly
E Quarterly differences model (1978-2006)	-0.06 (1st qtr) -0.11* (2nd qtr) -0.04 (3rd/4th qtr) -0.21	+0.01	-0.20	As medium run	+0.20	0.71/0.68	n = 112, quarterly
F Annual partial adjustment model (1974-2005)	-0.11***	n/a	n/a	-0.17	+0.07	0.84/0.82	n = 31, annual

(1) These R^2 are indicative only for Models A and D because these models were estimated using GLS (and an R^2 estimate was not available using this technique). They correspond to the OLS versions of Models A and D.

(2) Significance *** 0.1%, ** 1%, * 5%, `10%

C2.3 Criteria for final model selection

The main criteria for final model selection were:

- Statistical validity of residuals
  - Is there an expectation and/or evidence of stationarity in the residuals?
  - Are the residuals generally normally distributed?
  - Is there non-constant variance in the residuals?
  - Is there any evidence of autocorrelation in the residuals?
- Plausibility of coefficients
  - Are the results plausible and intuitive?
- Statistical power enabled by the sample
  - How large is the sample size available for this model?
  - How much variability is there in the period that the sample covers?

Because of the wide range of criteria considered, some judgement is required in weighing up the relative importance of the criteria described above.

C2.4 Preferred model: Model A

Before the analyses were carried out, Model A was assumed to be the ‘centrepiece’ of the research, because it was expected to produce robust and accurate estimates, for the reasons identified in Section 2.1.1. (Model F was also hypothesised to be potentially useful, but its usefulness depended on the extent to which stationarity in the error term could be established.)

Indeed, Model A did exhibit several favourable characteristics:

- Significant coefficients – Both the short-run petrol price elasticity and the short-run GDP per capita elasticity are statistically significant at 0.1% significance.
- Plausible coefficients – The petrol price elasticity estimates follow a plausible pattern: the short-run impact is -0.14 and this falls to -0.04, and become close to zero thereafter. The GDP per capita coefficient is positive, as would be expected. The intercept term is insignificant and close to zero, suggesting that the model, albeit simple, explains trends reasonably well.
- Stationarity in the error term – The process of differencing appears to have succeeded in causing stationarity in the error term: the hypothesis of stationarity in the error term was accepted at 1% significance, using an Augmented Dickey-Fuller test.
- Favourable Residual analysis – The ACF and PACF graphs indicate that the GLS estimation procedure has removed any major autocorrelation in the residuals. The residuals are distributed in a manner that is consistent with normality.

C2.5 Identification of preferred model

Table C2.2 shows diagnostic analysis and other information that were used to make a judgement in favour of Model A. The main advantages of Model A are that it exploits a large number of observations, it produces plausible results, and it gives strong evidence of stationarity in the residuals.

Table C2.2 Criteria relating to statistical validity and statistical power.

Model	Diagnostic Analysis				Other	
	Autocorrelation of residuals	**Stationarity of residuals**	**Normality of distribution**	**Constant variance of residuals**	**Sample size (n)**	**Sample period (years)**
A	No significant autocorrelation (except at the 16th lag)	Hypothesis of stationarity accepted at 1% significance	Normal distribution except for a few outliers	Decreasing variance	101	1978-2006 (28y)
B	High levels of autocorrelation	Not investigated due to autocorrelation ←	Not investigated due to autocorrelation ←	Not investigated due to autocorrelation ←	101	1978-2006 (28y)
C	No significant autocorrelation	Hypothesis of non-stationarity could not be rejected, even at 1% significance	Some non-normality in distribution	Approximately constant variance	31	1974-2005 (31y)
D	No significant autocorrelation (except at the 12th lag)	Hypothesis of non-stationarity could not be rejected, even at 10% significance	Normal distribution	Approximately constant variance	66	1999-2006 (6y)
E	No significant autocorrelation (except at the 16th lag)	Hypothesis of non-stationarity could not be tested as large number of explanatory variables	Normal distribution for central residuals but severe non-normality in the outliers	Approximately constant variance	112	1978-2006 (28y)
F	Not investigated as shows evidence of non-stationarity →	Risk of non-stationarity error term high due to use of non-stationary data The hypothesis of non-stationarity could not be rejected, even at 10% significance	Approximately normal distribution	Approximately constant variance	31	1974-2005 (31y)

C2.5.1 Models B, C and D

The advantages of Model A over Models B, C and D are as follows:

- Model B is inferior to Model A because it gives strong evidence of autocorrelation. This autocorrelation was resolved in Model A by estimating elasticities using generalised least squares (GLS), rather than ordinary least squares (OLS).

- Model C is inferior to Model A because it has considerably fewer observations (31 v 101). This may have contributed to the relatively low level of significances and the less plausible distribution between the short-run effect and the interim effect.
- Model D is inferior to Model A because it has fewer observations (66 v 101) and covers a shorter time period (6 years). However (somewhat surprisingly) Model D produced remarkably similar results in terms of coefficients, confidence intervals and the R^2. This similarity is comforting, especially since Model D uses a much smaller time period and monthly data, rather than quarterly data.

C2.5.2 Model E

Model E is not really comparable with Model A because it uses a different dependent variable. Model E was estimated because it potentially offered insights how quarterly changes in petrol prices affect quarterly changes in petrol consumption (whereas Model A looks only at the response of petrol consumption over a year). Model E produces plausible quarterly dynamics: if petrol prices increase by 1% in one quarter then petrol consumption falls by 0.06% in the same quarter, and then 0.11% in the next quarter. However the impacts of petrol prices tail off in following quarters.

Model E provides a useful insight into quarterly dynamics but it does not seem as useful as a substitute for the longer-term elasticity estimates provided by Model A. The model has a high R^2 but this is caused primarily by the contribution of highly significant seasonal dummies. Only one of the price elasticity coefficients is statistically significant. This could be due to the lack of parsimony (i.e. ability to explain behaviour with as simple a model as possible) as the model uses eight explanatory variables). Or it could be that quarterly changes in petrol consumption are less strongly related to petrol price changes than annual changes in petrol consumption.

C2.5.3 Model F

Model F was estimated because it is commonly used elsewhere in the transport literature and it potentially offered insights into long-run impacts of petrol prices.

However, Model F uses data that shows non-stationarity so the possibility of a non-stationarity in the error term is much higher than for any of the models above. Unfortunately, the possibility of a non-stationary error term could not be rejected, even at 10% significance, using an Augmented Dickey-Fuller test. Admittedly, this may be related to the small sample size of only 30 observations, so the model should not be discarded completely. However, by comparison, Model A seemed relatively more robust so it has been given more weight in this research.

C2.6 Multicolinearity

Most of the models used in this research are differences models. One of the advantages of differencing is that it reduces multicolinearity because it removes common trends in the data. For example, Table C2.3 shows that correlations of the explanatory variables in Models A and B are very low.

Table C2.3 Correlations between explanatory variables in Models A and B.

Explanatory variable	Petrol Index	Petrol Index (lagged 1 year)	GDP per capita
Petrol Index	1		
Petrol Index (lagged 1 year)	-0.03	1	
GDP per capita	0.02	0.04	1

In contrast, the correlations between the explanatory variables in Model F (Table C2.4) are very high because Model F uses undifferenced data. These high correlations may explain why the coefficient of the GDP per capita variable is insignificant.

Table C2.4 Correlations between explanatory variables in Model F.

Explanatory variable	Petrol Consumption (Lagged)	Petrol Index	GDP per capita
Petrol Consumption (Lagged)	1		
Petrol Index	-0.74	1	
GDP per capita	0.68	-0.63	1

C2.7 Models A and B – Four-quarter annual differences

C2.7.1 Data sources

The data sources used for this analysis consisted of the following:

- The two measures of quarterly petrol deliveries, both of which were examined:
  - The total tonnes of petrol delivered by oil companies in New Zealand, from March 1974 quarter to March 2006 quarter, were provided by SNZ.
  - The total tonnes of petrol delivered to fuel resellers and users of petrol (excluding petrol used for electricity generation or international transport), from March 1978 quarter to March 2006 quarter, were provided by the MED. Data were available back to March 1974 but the first four years of data were volatile and therefore probably not reliable.
- The petrol price index which was extrapolated backwards to March 1974 using other petrol price data:
  - The national CPI petrol price index, from March 1981 quarter to June 2006 quarter, on a quarterly basis, was provided by SNZ. The petrol price index measures price change of 91 octane petrol, 96 octane petrol and petrol additive, which were then averaged across each quarter.
  - The price of regular petrol, across New Zealand, from March 1974 quarter to March 2006 quarter. These data were provided by MED and had been obtained from SNZ and the Motor Trade Association (MTA).

> The MED price of regular petrol tracked the petrol price index very closely (except for a brief period from September 1986 to June 1991). Therefore, the price index was extrapolated backwards by assuming a linear relationship between the price index and the MED price of regular petrol.

The national consumer price index (CPI) from the March 1974 quarter to the June 2006 quarter, on a quarterly basis, was provided by SNZ (and obtained via the Reserve Bank of New Zealand).

A national gross domestic product (GDP) time series, as developed by Hall & McDermott (in press) of Victoria University, was used. The time series uses SNZ quarterly data from June 1977 to December 2005 and interpolates annual data before June 1977 using quarterly indicators. This time series has several limitations:

- Data before June 1977 is interpolated using indicators, as noted above.
- Data from June 1977 up to March 1987 uses a different method of adjusting inventories to data from March 1987 onwards.
- Any revisions to SNZ's current GDP series could create inconsistencies because those revisions are not reflected in the past data series.
- The data series methodology had not been peer-reviewed at the time it was incorporated into this research project.

The national GDP statistics, as provided by SNZ, were used to extend the Hall & McDermott series in that the growth rate observed from the December 2005 quarter to the March 2006 quarter applied to the December 2005 quarter of the Hall & McDermott series.

The quarterly population estimates from March 1991 to March 2006 were provided by SNZ. Annual population estimates before 1991 (also from SNZ) were interpolated to create a quarterly series from March 1974 to March 2006.

C2.7.2 Data manipulation

The quarterly petrol deliveries measures were divided by the number of days in each quarter so that the measure was consistent across quarters.

The quarterly petrol deliveries measures were also divided by population to create an additional ‘petrol deliveries per capita’ measure for empirical analysis.

C2.7.3 Models

The preferred models explained changes in petrol consumption *per capita* in terms of the following explanatory variables:

- Changes in the real petrol price index;
- Lagged changes in the real petrol price index;
- Changes in real GDP per capita.

The preferred models were fitted with data on petrol deliveries from the MED.

A *four-quarter annual differences* approach was adopted for this model: the dependent variable was the difference between petrol consumption per capita in a given quarter and petrol consumption per capita in the same quarter of the previous year. The explanatory variables were adjusted in the same manner.

OLS - The impacts of the variables described above were initially estimated using a standard regression technique, known as ordinary least squares (OLS). This model should produce unbiased estimates. However, the model exhibited autocorrelation in the residuals which would make the confidence intervals incorrect. To address this, a GLS model was developed.

GLS – The preferred model was produced through the application of generalised least squares (GLS) to the variables described above. GLS adjusts estimates and confidence intervals to take into account autocorrelation in the residuals.

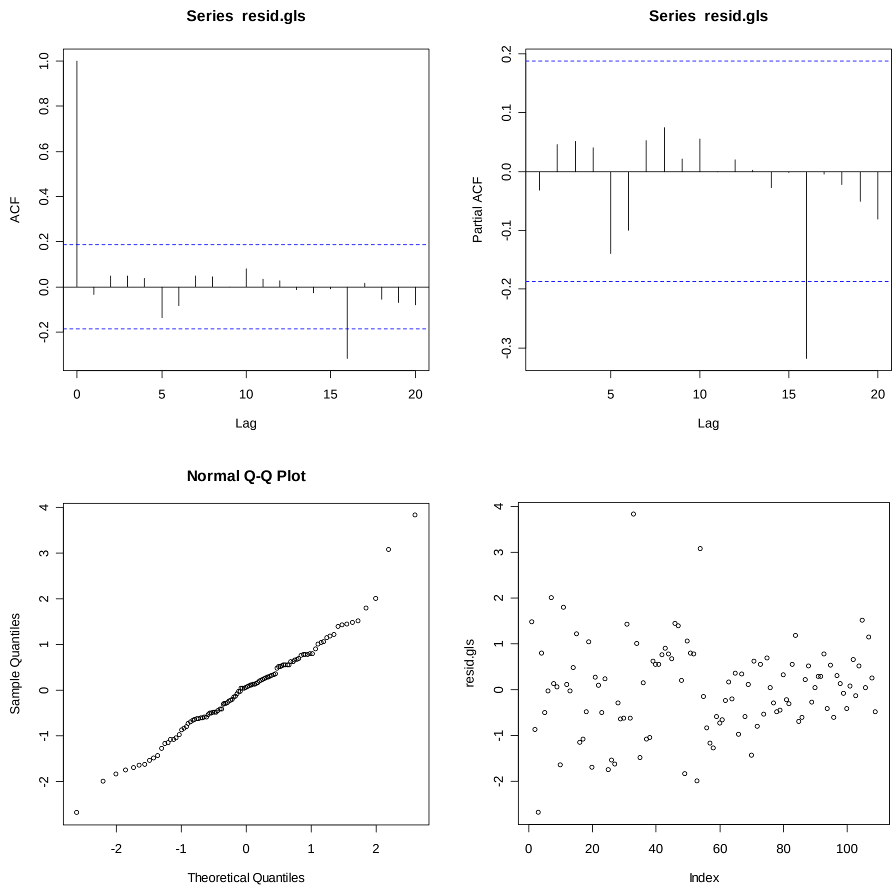
C2.7.4 OLS results (Model B)

```
Coefficients:
                   Estimate Std. Error t value Pr(>|t|)
(Intercept)       -0.002395   0.003140  -0.763  0.44735
petrol_index      -0.169245   0.028229  -5.995 2.90e-08 ***
lag1.petrol_index -0.058492   0.029349  -1.993  0.04886 *
gdp_capita         0.351816   0.110122   3.195  0.00185 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.02831 on 105 degrees of freedom
Multiple R-Squared: 0.3147,     Adjusted R-squared: 0.2952
F-statistic: 16.08 on 3 and 105 DF,  p-value: 1.136e-08
```

C2.7.5 GLS results (Model A)

The model was estimated using GLS, with autocorrelation approximated using an MA(4) error structure (selected by examination of ACF graphs and PACF graphs, as discussed in Section C1.4):

```
Coefficients:
Value  Std.Error   t-value p-value
(Intercept)       -0.0018086 0.00359188 -0.503515  0.6157
petrol_index      -0.1444647 0.03368354 -4.288880  0.0000
lag1.petrol_index -0.0446143 0.03526039 -1.265280  0.2086
gdp_capita         0.3208328 0.13365910  2.400381  0.0181

Augmented Dickey-Fuller Test
data:  resid
Dickey-Fuller = -5.295, Lag order = 4, p-value = 0.01
alternative hypothesis: stationary
```



C2.7.6 Comment on model validity

The residuals of the OLS model exhibited minor non-normality, autocorrelation and decreasing variance with time. This model is not discussed in greater depth here because the GLS model is preferable.

The residuals of the GLS model were much better (as expected). The GLS technique appeared to have addressed most of the autocorrelation.[10]

- The autocorrelation function (ACF) graph (top left) shows correlations between residuals and their lags; the closeness of the residuals to zero suggest that little correlation existed between a residual and residuals in the past.
- The Partial ACF (PACF) graph (top right) shows the extent to which a residual can be explained by lagged residuals. Again, little evidence shows that lagged residuals are related to future residuals.

In addition, the residuals become consistent with a normal distribution, as shown by the straight line in the Q-Q plot (bottom left). The residuals appeared to decrease with time (bottom right) which is not ideal, but not as serious as increasing residuals. If anything, this would appear to cause the confidence intervals to be too conservative.

Finally, the Augmented Dickey-Fuller Test was used to reject a null hypothesis of non-stationarity in the error term at 1% significance (1% critical value = -4.38). Evidence of stationarity in the residuals is strong, and therefore the risk of spurious estimates was judged to be very low.

C2.7.7 Other comments

The GLS model discussed above was fitted using deliveries data from the MED.

The GLS model was also fitted using petrol deliveries data from SNZ. The SNZ also has a reputation for good quality data but does not have the expertise of the MED. In any case the results were similar, especially when the time series was cropped to cover the same period as the MED data, as in Table C2.5.

Table C2.5 Comparison of models with differing data sources.

Data source	Time period	petrol_index	lag1.petrol_index
SNZ	Mar-74 to Mar-06	-0.128*** (+0.071)	-0.023 (+0.067)
	Mar-78 to Mar-06	-0.132** (+0.079)	-0.054 (+0.082)
MED	Mar-78 to Mar-06	-0.145*** (+0.066)	-0.045 (+0.069)

Significance *** 0.1%, ** 1%, *** 5%, `10%

Recall that the SNZ data is based on petrol deliveries by New Zealand oil companies. The MED data excludes petrol used for electricity generation or international transport. This distinction does not seem to have had an impact on the petrol price elasticities estimated in Table C2.5.

[10] A significant autocorrelation exists at about the 16th lag, suggesting that residuals 16 quarters apart are related, but this is possibly just an outlier and is not as problematic as correlations between residuals that are closer together.

C2.8 Model A incorporating impact of carless days

Upon advice from a referee, the impacts of the ‘carless day’ policy, from February 1979 to August 1980, were incorporated into Model A. Carless days were modelled using a dummy variable. The autocorrelation had to be modelled using an MA(5) error term because the model was not invertible with an MA(4) term.

The results of the inclusion of the ‘carless day’ policy dummy variable follow.

C2.8.1 OLS results

```
Coefficients:
                   Estimate Std. Error t value Pr(>|t|)
(Intercept)       -0.002493   0.003107  -0.803  0.42409
petrol_index      -0.164542   0.028047  -5.867 5.33e-08 ***
lag1.petrol_index -0.075134   0.030452  -2.467  0.01525 *
gdp_capita         0.349469   0.108950   3.208  0.00178 **
carless           -0.020225   0.011159  -1.813  0.07279 .
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.02801 on 104 degrees of freedom
Multiple R-Squared: 0.3357,     Adjusted R-squared: 0.3102
F-statistic: 13.14 on 4 and 104 DF,  p-value: 1.067e-08
```

The GLS version of the model (shown in Section C2.8.2) is more accurate. However, the OLS version of the model allows us to examine the impact of the ‘carless days’ policy on ‘goodness of fit’. The dummy has increased Model A’s R^2 (from 0.31 to 0.34) and the adjusted R^2 has increased from 0.30 to 0.31.

C2.8.2 GLS results (using MA(5) error term)

```
Coefficients:
                       Value  Std.Error   t-value p-value
(Intercept)       -0.0028027 0.00429479 -0.652578  0.5155
petrol_index      -0.1456843 0.03489129 -4.175378  0.0001
lag1.petrol_index -0.0540431 0.03655035 -1.478592  0.1423
gdp_capita         0.3884184 0.13982254  2.777938  0.0065
carless           -0.0152281 0.01440389 -1.057221  0.2929
```

The inclusion of the dummy variable has also had implications for the model coefficients produced by the GLS model. The short-run elasticity has increased from -0.14 to -0.15. The interim elasticity has increased from -0.04 to -0.05. The GDP per capita elasticity has increased from 0.32 to 0.39, and has now become statistically significant at 1%.

C2.9 Model A incorporating impacts of time on petrol consumption elasticities

The literature (see *Appendix D1. Petrol consumption elasticities*) is not definitive about whether petrol consumption elasticities change over time. Three studies break the data down into 'tranches': using this data, two studies find that elasticities increase with time, while one study finds that elasticities decrease with time.

Therefore, our own econometric model was modified to explore the impacts of time on elasticities. The SNZ petrol deliveries series was used for this specific exercise because it provided a longer time series (1974-2006) than the MED series (1978-2006).

C2.9.1 Breakdown by 'tranches'

The econometric model was first modified to replicate, in effect, the tranch-based studies referred to above. A dummy variable was used to divide the time series into a tranch for the first 15 years (1974 to 1989) and a tranch for the second 15+ years (1990 to 2006).[11]

```
Coefficients:
                                Value  Std.Error    t-value p-value
(Intercept)                -0.0022070 0.00388290 -0.5683982  0.5709
petrol_index               -0.0864031 0.04805006 -1.7981894  0.0747
lag1.petrol_index          -0.0200253 0.03350085 -0.5977546  0.5512
gdp_capita                  0.3663009 0.14432186  2.5380833  0.0125
petrol_index:X1st15yr_dummy -0.0658106 0.05157444 -1.2760305  0.2045
```

Initial analysis suggested that the short-run petrol price elasticity was relatively more elastic during the first 15 years. However, any differences between the two tranches were not statistically significant.

C2.9.2 Incorporation of time-trend variable

The econometric model was then modified to see if the short-run petrol price elasticity changed over time in any deterministic manner. To do this a time-trend variable was incorporated and interacted with the short-run price elasticity.

```
Coefficients:
                            Value  Std.Error    t-value p-value
(Intercept)            -0.0020986 0.00402225 -0.5217559  0.6028
petrol_index           -0.1672192 0.05970499 -2.8007574  0.0060
lag1.petrol_index      -0.0222722 0.03397999 -0.6554502  0.5135
gdp_capita              0.3685589 0.14795224  2.4910667  0.0142
petrol_index:time_trend  0.0007384 0.00088822  0.8313070  0.4075
```

[11] The dummy variable *X1st15yr_dummy* took the value 1 for observations in the first 15 years and the value 0 for the remaining observations.

The estimated impact of time on the short-run price elasticity was statistically insignificant. Furthermore, the estimated impact of time was remarkably close to zero. Thus taken at face value, the model results above imply that the short-run price elasticity becomes less elastic by 0.0007 units each year. The results strongly imply that there is no apparent tendency for elasticities to increase or decrease over time.

C2.10 Model A incorporating impacts of petrol price levels

The literature (see *Appendix D1. Petrol consumption elasticities*) is even more ambiguous about the impact of petrol price levels on petrol consumption elasticities.

Therefore, our econometric model was modified to explore the impact of petrol price levels on the short-run petrol price elasticity. The dummy variable represented the presence of petrol price levels above NZ$1.50 in March 2006.

```
Coefficients:
                            Value  Std.Error   t-value p-value
(Intercept)            -0.0022330 0.00407387 -0.548131  0.5847
petrol_index           -0.1396019 0.04145626 -3.367449  0.0010
lag1.petrol_index      -0.0242367 0.03421621 -0.708339  0.4802
gdp_capita              0.3816470 0.14809059  2.577119  0.0112
petrol_index:X1.5_dummy  0.0226643 0.03964162  0.571729  0.5686
```

The expectation was that the presence of petrol price above $1.50 might make consumption more responsive to petrol price elasticities. Interestingly, the results above indicate the opposite (although the impact of petrol price level on the short-run elasticity is statistically insignificant).

However, the approach used above is somewhat simplistic and was intended to be only exploratory. More sophisticated models may be worthy of exploration: examples include alternative interaction structures and models that assume a log-lin relationship between consumption and petrol prices.

C2.11 Model C – Year-on-year annual differences model

C2.11.1 Data sources

The data sources used for this analysis consisted of the following quarterly data series, which were aggregated (or averaged) to create annual series from 1974 to 2005:

- The total tonnes of petrol delivered by oil companies in New Zealand, from March 1974 quarter to March 2006 quarter, and provided by SNZ.
- The petrol price index was extrapolated backwards to March 1974 using other petrol price data:

  - The national CPI petrol price index, from March 1981 quarter to June 2006 quarter on a quarterly basis, provided by SNZ. The petrol price index measures price change of 91 octane petrol, 96 octane petrol and petrol additive, which were then averaged across each quarter.
  - The price of regular petrol, across New Zealand, from March 1974 quarter to March 2006 quarter. This data was provided by the MED and had been obtained from SNZ and the MTA.

    The MED price of regular petrol tracked the petrol price index very closely (except for a brief period from September 1986 to June 1991). Therefore, the price index was extrapolated backwards by assuming a linear relationship between the price index and the MED price of regular petrol.

- The national consumer price index (CPI), from March 1974 quarter to June 2006 quarter on a quarterly basis, was provided by SNZ (and obtained via the Reserve Bank of New Zealand).

The remaining data sources were provided in annual form:

- The national GDP estimates were obtained by combining a recent GDP series (covering 1988 to 2005) from SNZ with an older data series (covering 1974 to 2000) from the Treasury Long-Term Data Series. To do this, a linear relationship between the two series was estimated.
- The population estimates, representing population as at 31 December, from 1974 to 2005, were obtained from SNZ. There is a slight inconsistency in this series because measurement changed from 'de facto' to 'resident' in 1991.

C2.11.2 Data manipulation

The quarterly petrol deliveries measures were divided by the number of days in each year so that the measure was consistent between leap-years and non-leap-years.

C2.11.3 Models

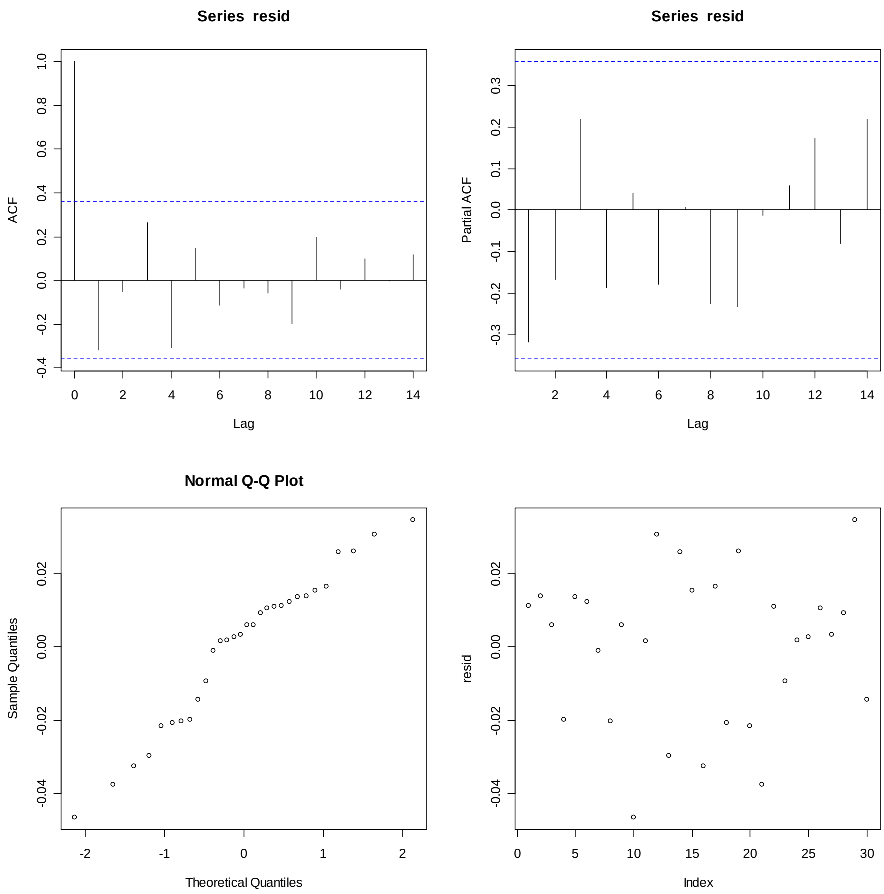
The variables used for the model were the same as those used for the four-quarter annual differences model (Models A, B) and the 12-month annual differences model (Model D):

- Changes in the real petrol price index;
- Lagged changes in the real petrol price index;
- Changes in real GDP per capita.

The dependent variable referred to changes in petrol consumption from one year to the next, and the explanatory variables were represented in the same form. The model was fitted satisfactorily using OLS. This approach has the disadvantage that the sample consists of only 30 observations.

C2.11.4 Results

```
Coefficients:
                   Estimate Std. Error t value Pr(>|t|)
(Intercept)        0.0006184  0.0047398   0.130   0.8972
petrol_index      -0.1335266  0.0569718  -2.344   0.0270 *
lag1.petrol_index -0.1032838  0.0459402  -2.248   0.0333 *
gdp_capita         0.1196940  0.2044854   0.585   0.5634
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.02207 on 26 degrees of freedom
Multiple R-Squared: 0.3366,     Adjusted R-squared: 0.2601
F-statistic: 4.397 on 3 and 26 DF,  p-value: 0.01248

Augmented Dickey-Fuller Test
data:  resid
Dickey-Fuller = -2.4274, Lag order = 3, p-value = 0.4085
alternative hypothesis: stationary
```



C2.11.5 Comment on model validity

This model exhibited favourable residual behaviour, even when fitted simply with OLS. The ACF and PACF plots illustrate the absence of discernible autocorrelation. The Q-Q plot provides some support for the assumption of normality and the trends could not be discerned from the plot of residuals against time.

The Augmented Dickey-Fuller test failed to reject a possibility of a non-stationary error term (10% critical value = -4.21). However, this could be due to the low power of the test given that a small sample size of 31 was used.

C2.12 Model D – 12-month annual differences model

C2.12.1 Data sources

The data sources used for this analysis consisted of the following:

- The total tonnes of petrol delivered (per month) to fuel resellers and users of petrol (excluding petrol used for electricity generation or international transport), from January 1999 to June 2006, and provided by the MED.
- Petrol price data from 1 January 1999 to 18 June 2006. The data consists of daily retail prices as advertised at major Wellington service stations, and was provided by the MED. The prices at the mid-point of each month were used as an explanatory variable.
- The national CPI from December 1999 quarter to June 2006 quarter, on a quarterly basis, provided by SNZ (and obtained via the Reserve Bank of New Zealand). The time series was then interpolated to create a monthly time series.
- The national GDP from December 1999 quarter to March 2006 quarter on a quarterly basis, provided by SNZ. The time series was then interpolated to create a monthly time series.
- The national population estimates from December 1999 quarter to March 2006 quarter on a quarterly basis, provided by SNZ. The time series was then interpolated to create a monthly time series.

C2.12.2 Data manipulations

The quarterly petrol deliveries measures were divided by the number of days in each month so that the measure was consistent across quarters.

The quarterly petrol deliveries measures were also divided by population to create an additional ‘petrol deliveries per capita’ measure for empirical analysis.

C2.12.3 Models

This model explained changes in petrol consumption per capita in terms of the following explanatory variables:

- Changes in the real regular petrol price;
- Lagged changes in the real regular petrol price;
- Changes in real GDP per capita.

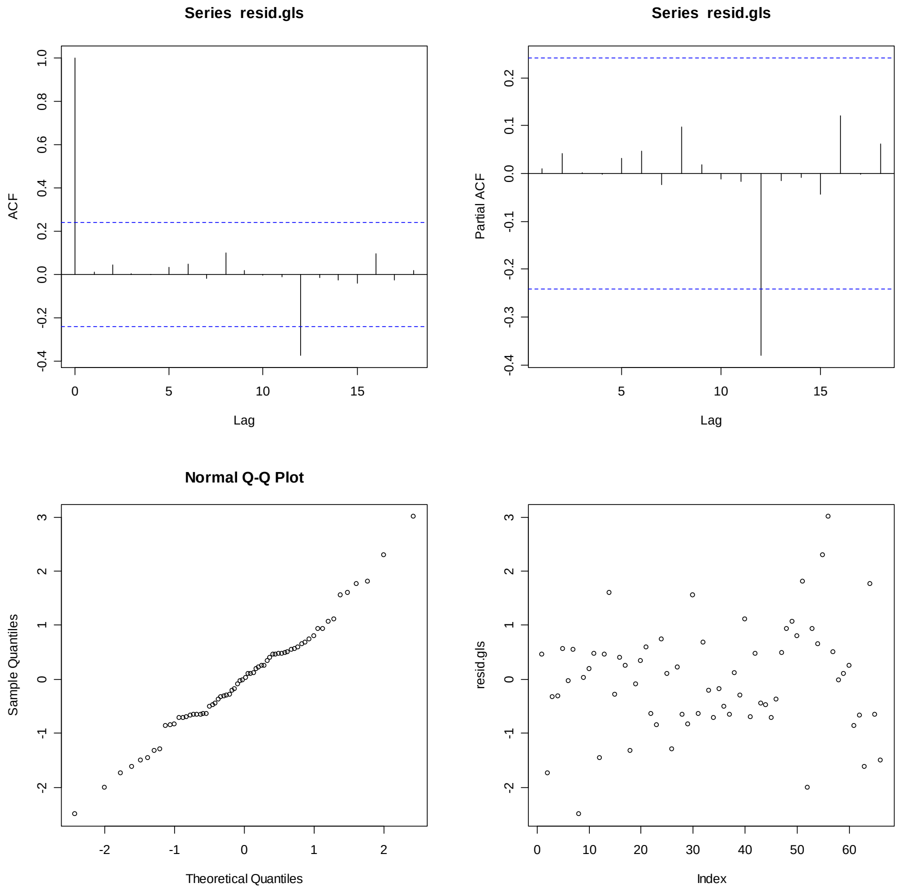
The impacts of the variables were estimated using a 12-month annual differences approach. Because of data limitations, this model covers a shorter time period, but the use of monthly data enables more observations to be made within each year of data.

The results of an initial OLS model are not shown as it did not address autocorrelation. To do this, a GLS technique was adopted.

C2.12.4 Results

The model was estimated using GLS, with autocorrelation approximated using an MA(4) error structure:

```
Coefficients:
                       Value  Std.Error   t-value p-value
(Intercept)       -0.0022603 0.00819085 -0.275954  0.7835
petrol_price      -0.1469643 0.02798409 -5.251707  0.0000
lag1.petrol_price  0.0035389 0.02576827  0.137336  0.8912
gdp_capita         0.5621172 0.31454823  1.787062  0.0788

Augmented Dickey-Fuller Test
data:  resid.gls
Dickey-Fuller = -3.0932, Lag order = 4, p-value = 0.1316
alternative hypothesis: stationarity
```



C2.12.5 Comment on model validity

The model exhibits pleasing generally pleasing patterns in the residuals, as shown by the ACF and PACF graphs above. Some autocorrelation occurs at the 12th lag (suggesting problems in differencing).

The distinctive straight line in the Q-Q plot strongly supports an assumption of normality. The plot of residuals against time suggests one can reasonably assume that variance is roughly constant through time.

However, the Augmented Dickey-Fuller test could not reject a hypothesis of non-stationarity in the error term, even at 10% significance (10% critical value = -4.02).

This model should not be given too much weight, but it produces comforting results, it performs better than any of the remaining models in the petrol elasticity section, and it produces similar results to the four-quarter annual differences model.

C2.13 Model E – Quarterly differences model

C2.13.1 Data sources

The data sources used for this analysis consisted of the following:

- The total tonnes of petrol delivered to fuel resellers and users of petrol (excluding petrol used for electricity generation or international transport), from March 1978 quarter to March 2006 quarter, and provided by the MED. Data were available back to March 1974 but the first four years of data were volatile and therefore probably not reliable.
- The petrol price index was extrapolated backwards to March 1978 using other petrol price data:
  - The national CPI petrol price index, from March 1981 quarter to June 2006 quarter on a quarterly basis, was provided by SNZ. The petrol price index measures price change of 91 octane petrol, 96 octane petrol and petrol additive, which were then averaged across each quarter.
  - The price of regular petrol, across New Zealand, from March 1974 quarter to March 2006 quarter. This data was provided by the MED and had been obtained from SNZ and the MTA. The MED price of regular petrol tracked the petrol price index very closely (except for a brief period from September 1986 to June 1991). Therefore, the price index was extrapolated backwards by assuming a linear relationship between the price index and the MED price of regular petrol.
- The national consumer price index (CPI), from March 1974 quarter to June 2006 quarter on a quarterly basis, was provided by SNZ (and obtained via the Reserve Bank of New Zealand).
- A national GDP time series, as developed by Hall & McDermott (in press) of Victoria University, was used. The time series uses SNZ quarterly data from June 1977 to December 2005 and interpolates annual data before June 1977 using quarterly indicators. This time series has several limitations:
  - Data before June 1977 is interpolated using indicators, as noted above.
  - Data from June 1977 up to March 1987 uses a different method of adjusting inventories to data from March 1987 onwards.

- Any revisions to SNZ's current GDP series could create inconsistencies because those revisions are not reflected in the past data series.
- The data series methodology had not been peer reviewed at the time it was incorporated into this research project.

- The national GDP statistics, as provided by SNZ, were used to extend the Hall & McDermott series: the growth rate observed from the December 2005 quarter to the March 2006 quarter was applied to the December 2005 quarter of the Hall & McDermott series.
- The quarterly population estimates from March 1991 to March 2006 were provided by SNZ. Annual population estimates before 1991 (also from SNZ) were interpolated to create a quarterly series from March 1974 to March 2006.

C2.13.2 Data manipulation

The quarterly petrol deliveries measures were divided by the number of days in each quarter so that the measure was consistent across quarters.

The quarterly petrol deliveries measures were also divided by population to create an additional 'petrol deliveries per capita' measure for empirical analysis.

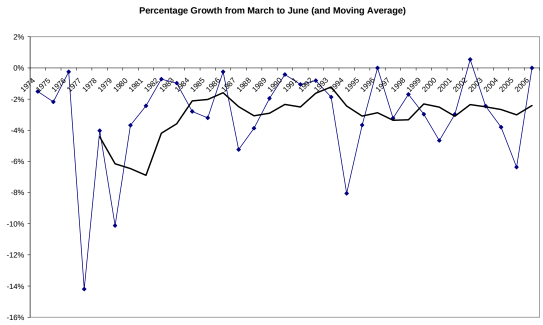
C2.13.3 Models

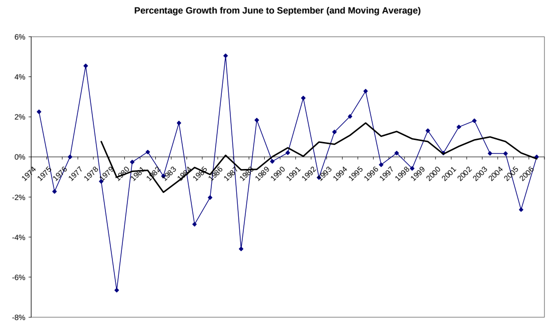
This model was less parsimonious than any of the other models that were fitted. The model explained changes in petrol consumption per capita *from one quarter to the next* in terms of changes in the following explanatory variables:

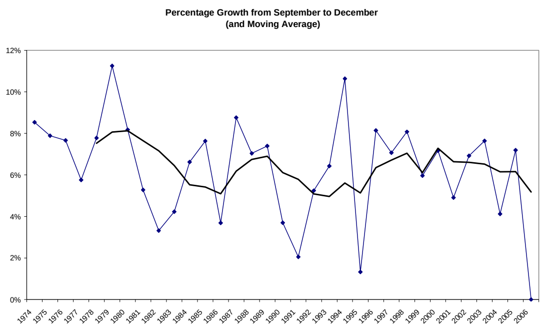
- The change in the real petrol price index over the same quarter;
- The change in the real petrol price index over the preceding quarter;
- The change in the real petrol price index from the quarter a year before to the quarter two quarters previously;
- The change in the real petrol price index from the quarter two years before and the quarter one year previously;
- The change in real GDP per capita over the same quarter;
- Dummies representing the impacts of June, September and December quarters on growth in petrol consumption in any given quarter.

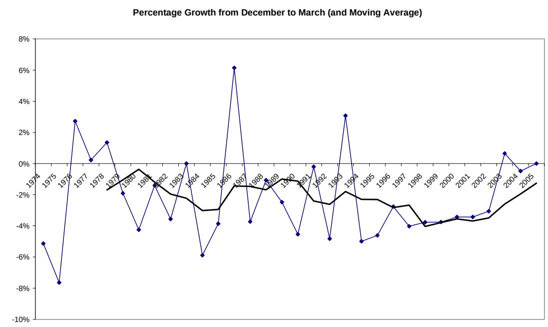
For the inclusion of dummies to be valid, the assumption was made that seasonal effects had a predictable and constant impact on changes in petrol consumption. The figures below validate this assumption because they show that the growth rates from one quarter to the next are roughly constant, regardless of the year examined.

The model was initially fitted using OLS and then with GLS (to adjust for autocorrelation).





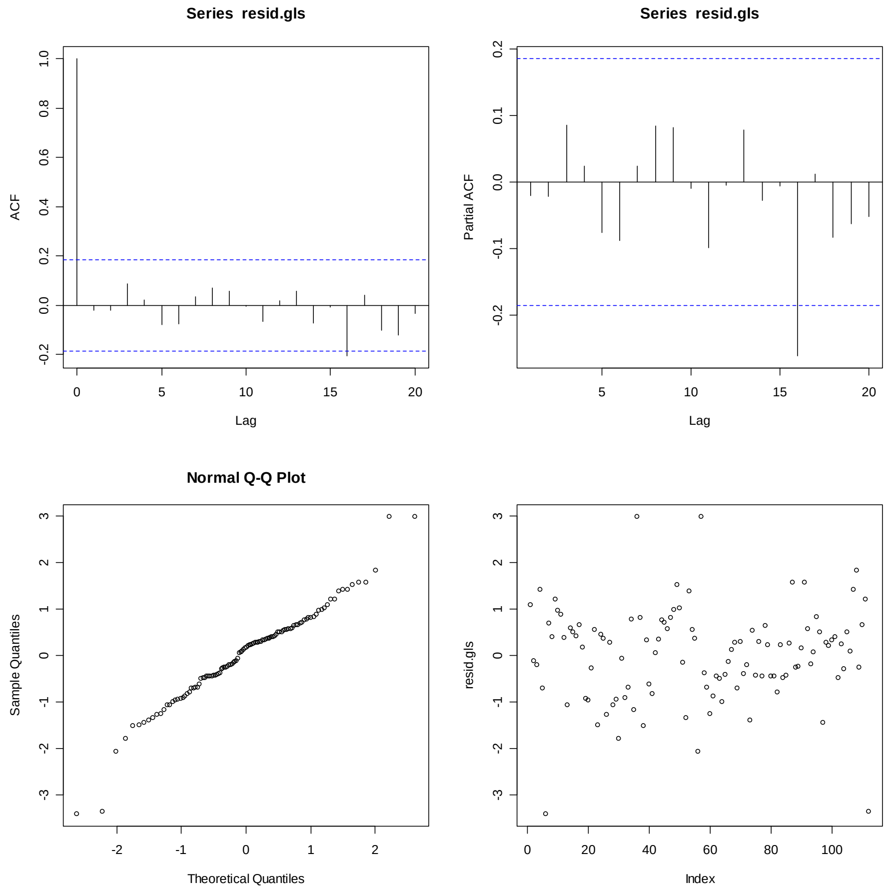




C2.13.4 Results

A GLS model was fitted, with autocorrelation approximated using an MA(1) error structure (selected via examination of ACF graphs and PACF graphs):

```
Coefficients:
                         Value  Std.Error    t-value p-value
(Intercept)         0.05872669 0.00479524  12.246862  0.0000
price_index        -0.06100552 0.04778798  -1.276587  0.2046
lag1.price_index   -0.11047752 0.05434393  -2.032932  0.0446
lag2.3.price_index -0.03634612 0.02700782  -1.345763  0.1813
lag4.7.price_index  0.00818674 0.01273170   0.643020  0.5216

gdp_capita          0.20377441 0.13626010   1.495481  0.1378
Jun                -0.06839731 0.00827992  -8.260625  0.0000
Sep                -0.09642712 0.00696220 -13.850098  0.0000
Dec                -0.07108834 0.00834647  -8.517169  0.0000

Augmented Dickey-Fuller Test
data:  resid.gls
Dickey-Fuller = -4.525, Lag order = 4, p-value = 0.01
alternative hypothesis: stationary
```



C2.13.5 Comment on model validity

The ACF and PACF graphs indicate that the autocorrelation has been addressed. There was some autocorrelation at the 16th lag but this could be coincidental.

The Q-Q plot indicates some non-normality at the tails. The last plot (bottom right) shows the interrelationship between residuals and time, with some suggestion of decreasing variance with time.

However, the main problems with this model include its lack of parsimony (i.e. ability to explain behaviour with as simple a model as possible), its insignificant petrol price elasticities, and inconsistencies with the other petrol price elasticity models.

C2.14 Model F – Annual partial adjustment model

C2.14.1 Data sources

The data sources used for this analysis consisted of the following quarterly data series, which were aggregated (or averaged) to create annual series from 1974 to 2005:

- The total tonnes of petrol delivered by oil companies in New Zealand, from the March 1974 quarter to the March 2006 quarter, were provided by SNZ.

- The petrol price index was extrapolated backwards to March 1974 using other petrol price data:
  - The national CPI petrol price index, from the March 1981 quarter to the June 2006 quarter on a quarterly basis, provided by SNZ. The petrol price index measures price change of 91 octane petrol, 96 octane petrol and petrol additive, which are then averaged across each quarter.
  - The price of regular petrol, across New Zealand, from the March 1974 quarter to the March 2006 quarter. This data was provided by the MED and had been obtained from SNZ and the MTA. The MED price of regular petrol tracked the petrol price index very closely (except for a brief period from September 1986 to June 1991). Therefore, the price index was extrapolated backwards by assuming a linear relationship between the price index and the MED price of regular petrol.
- The national CPI, from the March 1974 quarter to the June 2006 quarter on a quarterly basis, provided by SNZ (and obtained via the Reserve Bank of New Zealand).

The remaining data sources were provided in annual form:

- The national GDP estimates obtained by combining a recent GDP series (covering 1988 to 2005) from SNZ with an older data series (covering 1974 to 2000) from the Treasury Long-Term Data Series. To do this, a linear relationship between the two series was estimated.
- The population estimates, representing population as at 31 December, from 1974 to 2005, obtained from SNZ. There is a slight inconsistency in this series because measurement changed from 'de facto' to 'resident' in 1991.

C2.14.2 Data manipulation

The quarterly petrol deliveries measures were divided by the number of days in each year so that the measure was consistent between leap-years and non-leap-years.

C2.14.3 Models

The dependent variable for this model consisted of petrol consumption (logged). The explanatory variables included the following (all logged):

- The lag of petrol consumption per capita;
- The real petrol price index;
- Real GDP per capita.

This model is used to estimate three parameters:

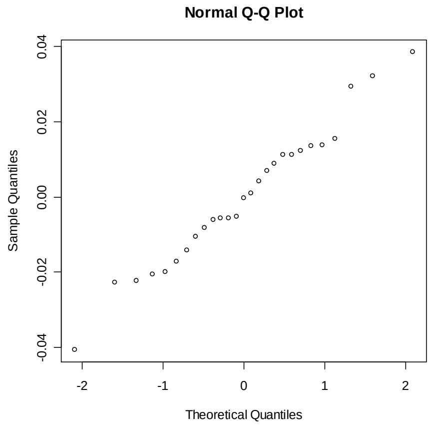
- The short-run petrol price elasticity;
- The speed of adjustment;
- The long-run petrol price elasticity.

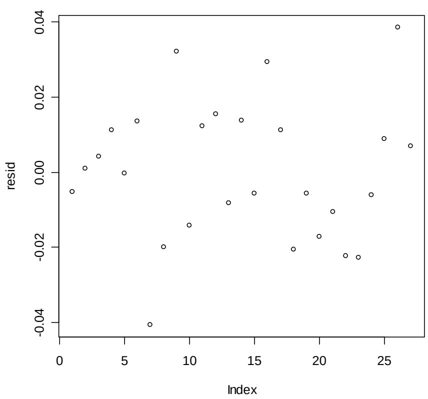
In this model, the long-run petrol price elasticity is assumed to be a function of the short-run petrol price elasticity and the speed of adjustment. The model was fitted satisfactorily using OLS.

This model approach has the disadvantage that the sample consists of only 30 observations.

C2.14.4 Results

```
Coefficients:
                          Estimate Std. Error t value Pr(>|t|)
(Intercept)                0.07110    0.14173   0.502 0.619956
lag1.petrol_del_capita_ns  0.37550    0.12992   2.890 0.007506 **
petrol_index_ns           -0.11057    0.02726  -4.056 0.000382 ***
gdp_capita_ns              0.06824    0.04704   1.451 0.158438
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.01895 on 27 degrees of freedom
Multiple R-Squared: 0.8371,     Adjusted R-squared: 0.819
F-statistic: 46.26 on 3 and 27 DF,  p-value: 8.982e-11

studentized Breusch-Pagan test
data:  results
BP = 2.3367, df = 3, p-value = 0.5055

Augmented Dickey-Fuller Test
data:  resid
Dickey-Fuller = -2.0263, Lag order = 2, p-value = 0.5624
alternative hypothesis: stationary
```





C2.14.5 Comment on model validity

The partial adjustment model exhibited normality of the residuals in the Q-Q plot. The residuals appear constant throughout time in the plot of residuals against time. In addition, the Breusch-Pagan test failed to detect first order autocorrelation.

However, the Augmented Dickey-Fuller test failed to reject the possibility of non-stationarity in the residuals (10% critical value = -4.21). This is particularly concerning because this model uses data that are definitely non-stationary; therefore the possibility of non-stationarity in the error term is higher than it would have been with the differences models.

C3 Traffic volume elasticities

C3.1 52-week annual differences

C3.1.1 Data sources

The data sources used for this analysis consisted of the following:

- Transit NZ Count data from 1 January 2002 to 18 June 2006. The data consists of weekly counts on all site-types that provide weekly data (telemetry, loop, and ATMS or Automatic Traffic Management System).
- Petrol price data from 1 January 2002 to 18 June 2006. The data consists of daily retail prices as advertised at major Wellington service stations. The data was provided by the MED.
- The national CPI from the March 1997 quarter to the June 2006 quarter. The index on a quarterly basis was provided by SNZ (and obtained via the Reserve Bank of New Zealand).
- The national GDP from the March 1997 quarter to the March 2006 quarter on a quarterly basis, provided by SNZ.
- The national population estimates from the March 1997 quarter to the March 2006 quarter on a quarterly basis, provided by SNZ. The time series was then interpolated to create a weekly time series.

C3.1.2 Data manipulation

The count data was segregated to create four categories: (1) counts for total cars; (2) counts for cars on rural roads; (3) counts for cars on urban roads during peak times; and (4) counts for cars on urban roads during off-peak times:

- The ‘car’ counts were identified by isolating counts for vehicles of 0.5 to 5.5 metres length.
- The ‘urban’ sites were distinguished from ‘rural’ sites by Transit NZ, based on vehicle speeds. However, any Auckland-based ATMS were deemed to be ‘urban’ despite high speeds that are more likely due to the presence of highways.
- The ‘car’ counts on urban sites were further divided into ‘peak’ (7-9am, 4-6pm) and ‘off-peak’ data.

The Transit NZ Count data was problematic as all of the sites had weeks in which data were missing:

- The Auckland-based sites were not introduced until the beginning of 2003;
- The Auckland-based sites server went down around May 2004;
- The Auckland-based sites were updated only until 24 April 2006, while the other sites were updated until 18 June 2006;
- All the sites had random incidents of missing data: the cause of this missing data could not be explicitly identified, but the most likely causes include roadworks or mechanical failure;

- Most sites produced missing data during the weeks in which daylight saving was added or removed; the inclusion of 23- or 25-hour days created problems with automated computation systems.

The following solutions were employed to address these missing data problems:

- The weeks in which daylight saving was added or removed were excluded from the analysis.
- The remaining weeks in which data was missing were 'filled in' for each site, for example, consider site '100130':
  1. The missing value for site '100130' was estimated as a function of site '100212' in that same week.[12]
  2. The missing value for site '100130' was estimated as a function of site '100265' in that same week.
  3. This process continued so that the missing value for site '100130' was estimated as a function of all other sites.
  4. Finally, the predictions of each of these estimates were averaged to produce an estimate for the missing value for site '100130'.[13] The impacts of these 'interpolated' values are shown in the charts in Figure C3.1.

In addition, the other variables were estimated and/or manipulated to create a weekly time series analysis of the period from 1 January 2002 to 18 June 2006

- The *ANZ Quarterly Economic Forecasts for June 2006* were used to forecast GDP for the June 2006 quarter.
- GDP was interpolated to produce a daily GDP series. Thereby, GDP was estimated for each week.
- Similarly, CPI was interpolated to produce a daily CPI series. Thereby, CPI was estimated for each week and used to deflate the daily petrol price series.

The traffic count data and GDP were also divided by population to create 'per capita' measures for empirical analysis.

C3.1.3 Models

The following models were fitted so that they could be compared to the preferred model, i.e. the four-quarter annual differences model. The model fitted was a 52-week annual differences model, and 52-week changes in vehicle counts were explained in terms of the following explanatory variables:

---

12 The function was a linear parameter, based on the ratio of counts in site '100130' to counts in site '100212' (for all weeks where counts were available for both sites).

13 To be specific, a weighted average was used, where the weights were the counts in each of the predictor sites. An unweighted average was used initially but this appeared to be too susceptible to the behaviour of sites with low counts.

- Changes in real regular petrol prices over 52 weeks;
- Lagged changes in real regular petrol prices over the previous 52 weeks;
- Changes in GDP per capita over 52 weeks.

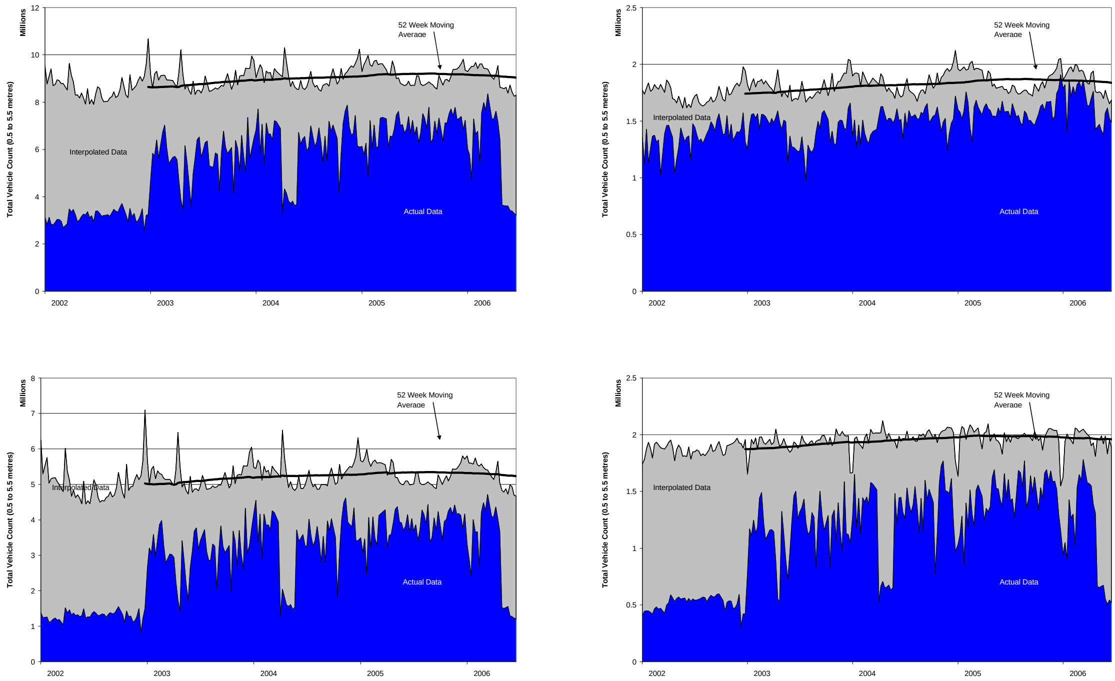


Figure C3.1 Actual and interpolated total vehicle counts (vehicles up to 5.5-m lengths), from top left and clockwise: total, rural, off-peak, and peak, for 2002-2006.

In addition to providing symmetry with the four-quarter annual differences model, this model structure can be justified because the petrol price impacts beyond the first lag were insignificant.

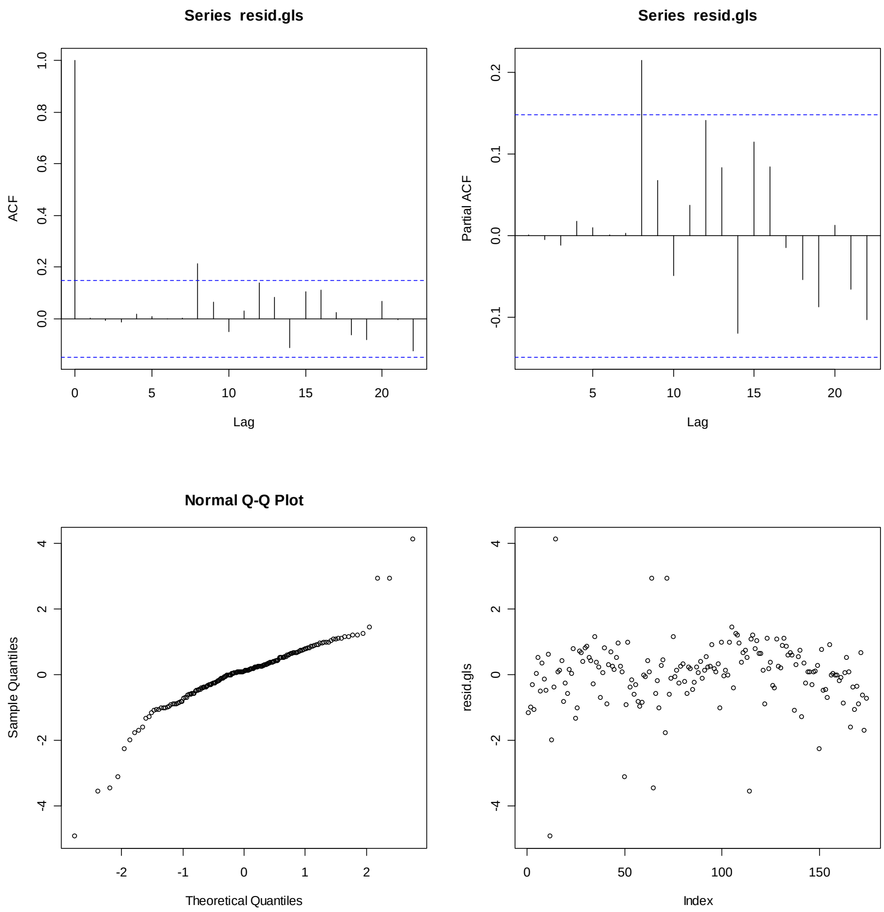
All the models were estimated using GLS because the OLS models indicated autocorrelation.

One peer reviewer raised concerns about the effectiveness of the 52-week annual differences model in the presence of a leap-year in 2004. Because of this leap-year, the weeks in 2004 do not correspond perfectly with the weeks in 2003 and 2005; for example, we calculate the difference between a week beginning 5/3/06 and a week beginning 4/3/04. We acknowledge that this is not ideal and it should be avoided, where possible, in future empirical analysis of traffic counts, but consider that any occasional discrepancies will have a low influence given the large number of observations available in the dataset.

C3.1.4 Results – Total counts

Estimated using GLS, with autocorrelation approximated using an MA(4) error structure:

```
Coefficients:
                        Value Std.Error   t-value p-value
(Intercept)        0.01763369 0.0091041  1.936898  0.0544
petrol_price      -0.21986653 0.0334120 -6.580474  0.0000
lag1.petrol_price -0.08377315 0.0431741 -1.940356  0.0540
gdp_capita         0.14299567 0.3906219  0.366072  0.7148

Augmented Dickey-Fuller Test
data:  resid.gls
Dickey-Fuller = -4.9991, Lag order = 5, p-value = 0.01
alternative hypothesis: stationary
```

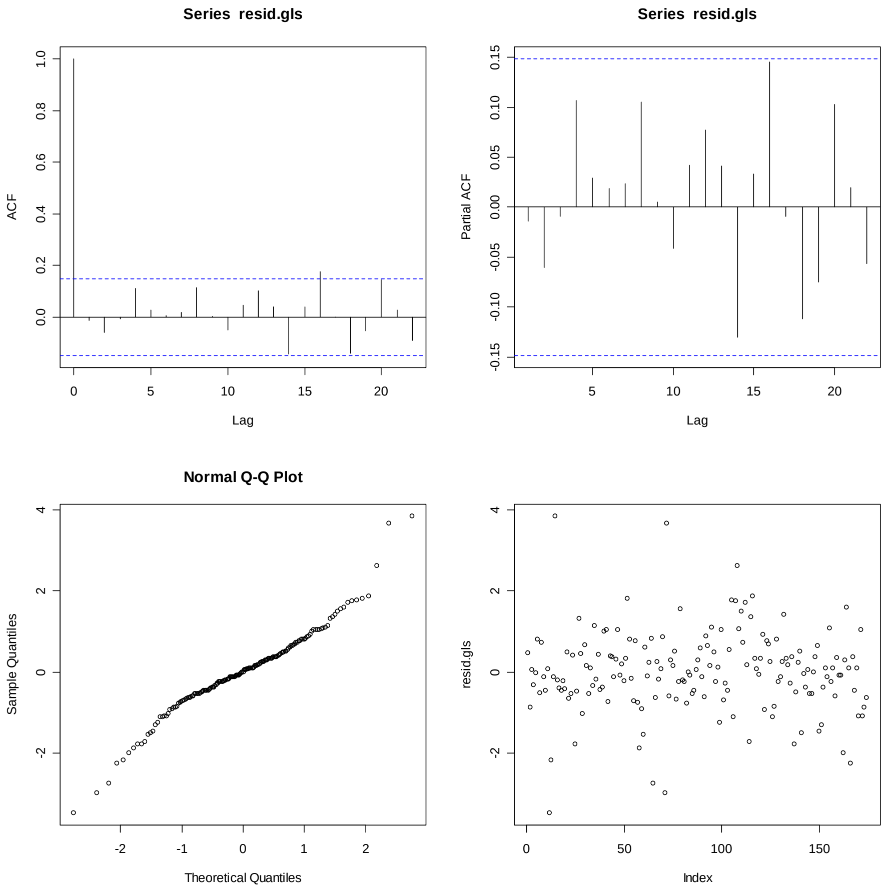


C3.1.5 Results – Rural counts

Estimated using GLS, with autocorrelation approximated using an MA(1) error structure:

```
Coefficients:
                        Value Std.Error   t-value p-value
(Intercept)         0.0024437 0.0092141  0.265218  0.7912
petrol_price       -0.1594394 0.0329389 -4.840463  0.0000
lag1.petrol_price  -0.0329260 0.0416648 -0.790259  0.4305
gdp_capita          0.6518980 0.3941354  1.653995  0.1000
```

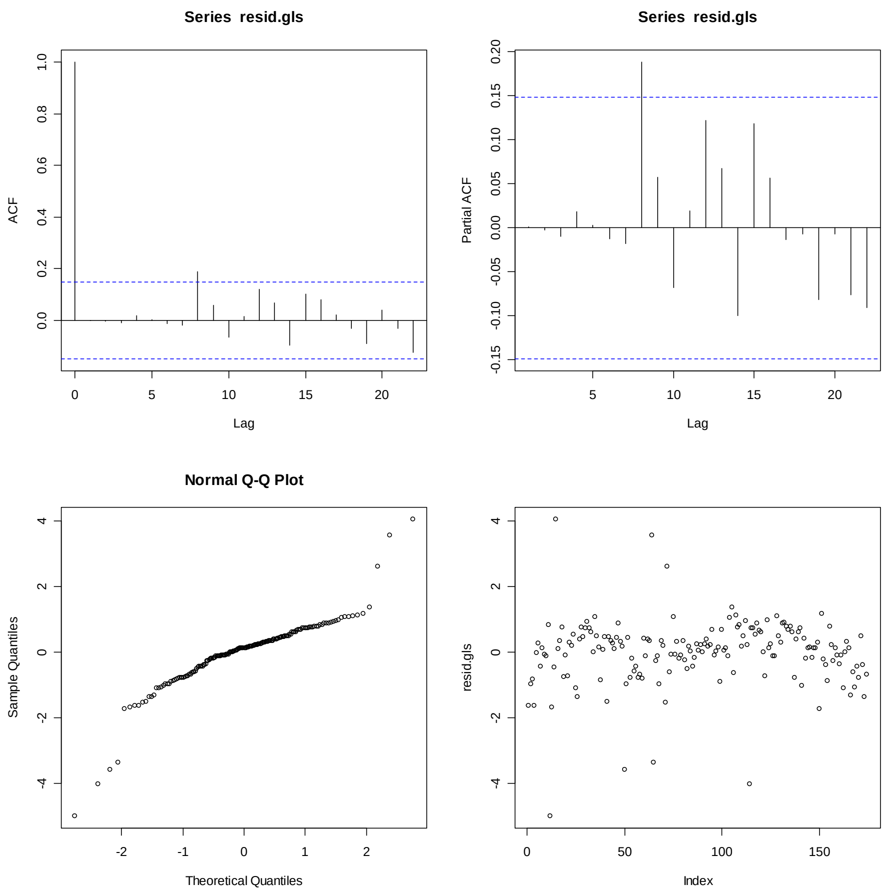
```
Augmented Dickey-Fuller Test

data:  resid.gls
Dickey-Fuller = -4.6351, Lag order = 5, p-value = 0.01
alternative hypothesis: stationary
```



C3.1.6 Results – Off-peak counts

Estimated using GLS, with autocorrelation approximated using an MA(4) error structure:

```
Coefficients:
                        Value Std.Error   t-value p-value
(Intercept)        0.02556063 0.0108663  2.352293  0.0198
petrol_price      -0.26592421 0.0405142 -6.563729  0.0000
lag1.petrol_price -0.08921539 0.0528342 -1.688592  0.0931
gdp_capita        -0.09910733 0.4675593 -0.211967  0.8324

Augmented Dickey-Fuller Test
data:  resid.gls
Dickey-Fuller = -5.2574, Lag order = 5, p-value = 0.01
alternative hypothesis: stationary
```

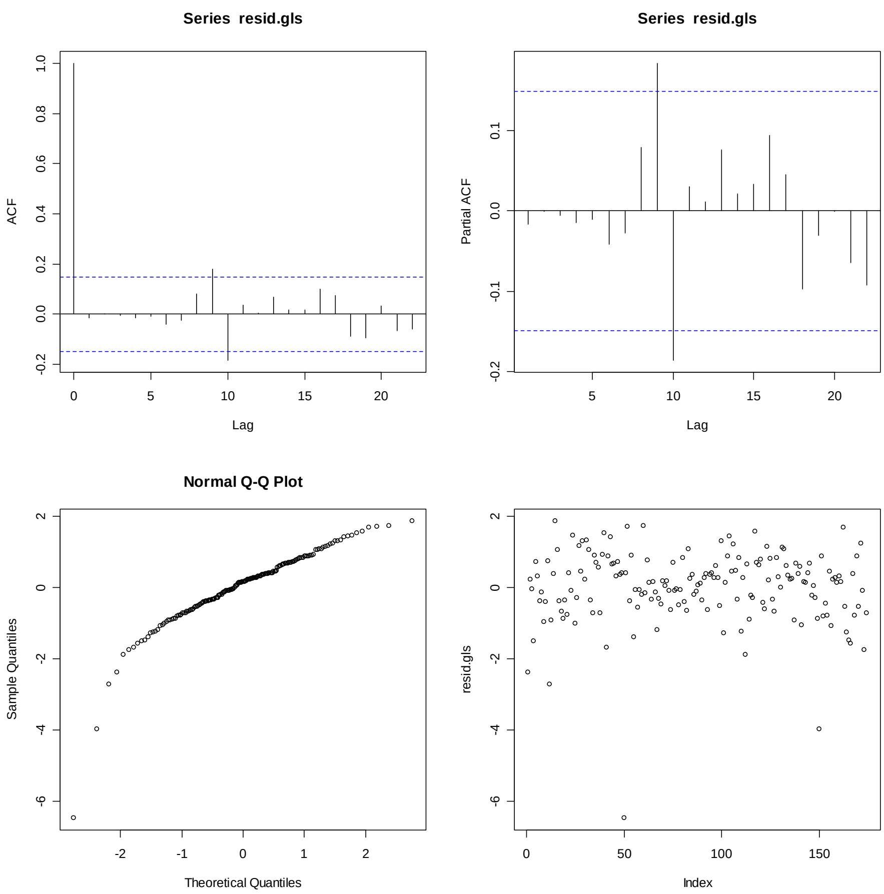


C3.1.7 Results – Peak counts

Estimated using GLS, with autocorrelation approximated using an MA(4) error structure:

```
Coefficients:
                         Value Std.Error   t-value p-value
(Intercept)         0.00798503 0.0101086  0.789922  0.4307
petrol_price       -0.10368413 0.0354571 -2.924215  0.0039
lag1.petrol_price  -0.18376916 0.0444229 -4.136814  0.0001
gdp_capita          0.27275173 0.4316699  0.631853  0.5283
```

```
Augmented Dickey-Fuller Test
data:  resid.gls
Dickey-Fuller = -5.5556, Lag order = 5, p-value = 0.01
alternative hypothesis: stationary
```

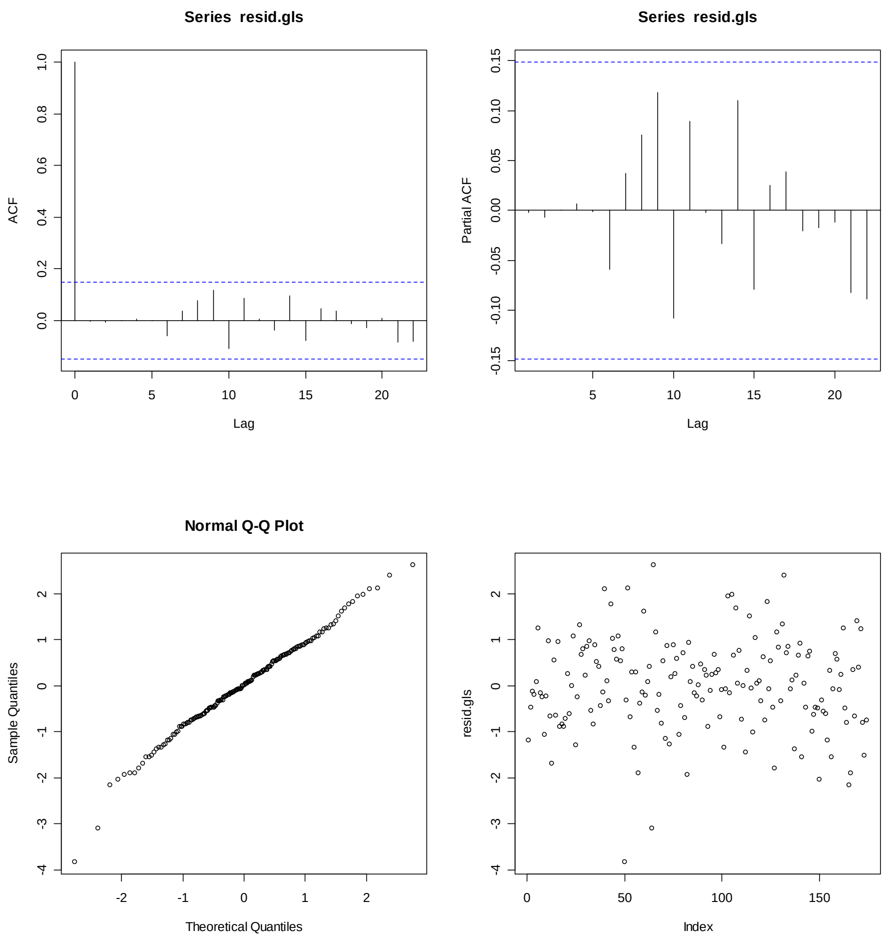


C3.1.8 Results – Peak counts (using only reliable sites)

Estimated using GLS, with autocorrelation approximated using an MA(4) error structure:

```
Coefficients:
                        Value  Std.Error   t-value p-value
(Intercept)         0.0031529 0.00661762  0.476442  0.6344
petrol_price       -0.0934532 0.02337411 -3.998148  0.0001
lag1.petrol_price -0.1501225 0.02947397 -5.093391  0.0000
gdp_capita          0.4750588 0.28262513  1.680879  0.0946
```

```
Augmented Dickey-Fuller Test
data:  resid.gls
Dickey-Fuller = -5.4376, Lag order = 5, p-value = 0.01
alternative hypothesis: stationary
```



C3.1.9 Model estimates

The estimates for each of the preferred car traffic volume models are shown in Table C3.1.

Table C3.1 Elasticity estimates.[1]

Dataset	Petrol Price Elasticities			GDP per capita elasticities (0-1 years)	R^2 / Adjusted R^2 [3]
	Short-run effect (0-1 year)	Interim effect (1-2 years)	Medium-run effect (0-2 years)		
Total	-0.22*** (±0.07)	-0.08 (±0.08)	-0.30*** (±0.11)	0.14 (±0.78)	0.20/0.19
Rural	-0.16*** (±0.06)	-0.03 (±0.08)	-0.19*** (±0.11)	0.65' (±0.77)	0.23/0.22
Urban Off-Peak	-0.27*** (±0.08)	-0.09' (±0.10)	-0.36*** (±0.13)	-0.10 (±0.93)	0.14/0.13
Urban Peak	-0.10** (±0.07)	-0.18*** (±0.09)	-0.29*** (±0.12)	0.27 (±0.84)	0.24/0.23
Urban Peak – Reliable Sites[2]	-0.09*** (±0.05)	-0.15*** (±0.06)	-0.24*** (±0.08)	0.48' (±0.55)	0.32/0.32

(1) All models were annual difference models, using GLS.
Significance of results denoted ***0.1%, **1%, *5%, '10%.
The coefficient is shown at the top of each cell and the 95% margin of error is shown in brackets.
The estimates pertain to the period from January 2003 to June 2006.

(2) This dataset excludes sites with a high proportion of missing data (including most of the Auckland area sites), as preliminary analysis indicated that an outlier was unduly influencing the estimates.

(3) The R^2 provided are indicative because these models were estimated using generalised least squares (and an R^2 estimate was not available using this technique). The R^2 provided above correspond to the OLS versions of the models above.

C3.1.10 Comment on model validity

Detailed analysis showed that the residuals appeared to show stationarity. Using the Augmented Dickey-Fuller Test, the possibility of non-stationarity in the residuals was rejected at 1% significance (critical value -4.64) for all of the sites except the rural sites, for which the hypothesis of non-stationarity in the error term was nearly rejected at 1% significance.

Despite the favourable result with respect to stationarity of the residuals, the models for all the sites exhibited undesirable outliers. These outliers affected the normality of the ends of the tails.

Table C3.2 Criteria relating to statistical validity and statistical power.

Dataset	Diagnostic Analysis				Other	
	Autocorrelation of residuals	Stationarity of residuals	Normality of distribution	Constant variance of residuals	Sample size (n)	Sample period
Total (all sites)	No significant autocorrelation at lower lags; some auto-correlation at higher lags(esp. the 8th lag)	Hypothesis of stationarity accepted at 1% significance	Non-normality at extremes of distribution: tails are 'too heavy' to be normal	Roughly constant variance; some evidence of outliers earlier in the series	174	2002 to 2006
Rural (all sites)	No significant autocorrelation, but perhaps slightly higher at higher lags	Hypothesis of stationarity nearly accepted at 1% significance: (observed value = -4.635; critical value of -4.64)	Distribution reasonably normal, but some non-normality in the tails	Roughly constant variance; some evidence of outliers	174	2002 to 2006
Urban off-peak (all sites)	No significant autocorrelation, but perhaps slightly higher at higher lags	Hypothesis of stationarity accepted at 1% significance	Non-normality at extremes of distribution: tails are 'too heavy' to be normal	Roughly constant variance; some evidence of outliers earlier in the series	174	2002 to 2006
Urban peak (all sites)	No significant autocorrelation, except at 9th and 10th lags	Hypothesis of stationarity accepted at 1% significance	Non-normality at extremes of the distribution, especially at lower end; this non-normality was especially concerning as it was asymmetric	Roughly constant variance except for a few outliers at the lower end of distribution	174	2002 to 2006
Urban peak (reliable sites)	No significant autocorrelation, but perhaps slightly higher at higher lags	Hypothesis of stationarity accepted at 1% significance	Normal distribution	Roughly constant variance	174	2002 to 2006

For the urban-peak site, the few outliers were particularly concerning because they caused asymmetric non-normality. This appears to have been related to the interpolation method, which made its estimates untrustworthy. Therefore, the model was re-estimated as a dataset that excluded sites with a high proportion of missing data (including most of the Auckland area sites), as preliminary analysis indicated that an outlier was unduly influencing the estimates.

The resultant peak 'limited' traffic volume model performed very well, as noted by favourable descriptions of residuals in Table C3.2. The rural traffic volume model (for all sites) also produced favourable residuals.

The coefficient on GDP is insignificant for all the sites, and is probably due to insufficient variation in GDP per capita over the six-year period being studied.

C3.1.11 Comment on multicolinearity

An alternative culprit for the insignificant coefficient on GDP per capita was multicolinearity. Table C3.3 shows reasonable correlation between changes in GDP per capita and the lagged changes in petrol price, although not at the levels that usually cause multicolinearity.

Table C3.3 Correlations between explanatory variables.

Explanatory variable	Petrol price	Petrol price (lagged)	GDP per capita
Petrol Price	1		
Petrol Price (lagged)	-0.01	1	
GDP per capita	-0.14	-0.39	1

C4 Public transport cross-elasticities

C4.1 Wellington Bus Patronage – Four-quarter annual differences

C4.1.1 Introduction

The preliminary phase of analysis included time-series analysis of recent patronage data; this data consisted of patronage from 25 July 1999 to 28 May 2006.

This preliminary analysis produced plausible estimates for the cross-price elasticity of demand, but these estimates were not significant. Furthermore, the sign of the fare elasticity was counter-intuitive and the model appeared to exhibit negative autocorrelation.

These problems prompted the development of a longer time series that incorporated patronage data from a previous Booz Allen Hamilton study (BAH 2001).

C4.1.2 Data sources

The data sources used for this analysis consisted of the following:

- StageCoach Wellington patronage and revenue time series data:
  - The first tranch of data had been provided to BAH for the Wellington Fares Study in June 2001. This data was provided by StageCoach and consisted of weekly patronage and revenue across Wellington city routes, from 5 January 1997 to 30 December 2002.
  - The second tranch of time-series data was recently provided to BAH by StageCoach. The data was presented in 4-weekly accounting periods, from 25 July 1999 to 28 May 2006, and consisted of patronage and revenue across Wellington city routes.
- The Wellington City (territorial authority) population estimates as at 30 June, from 1996 to 2005 on an annual basis, provided by SNZ. The population for 30 June 2006 was forecast based on the assumption that growth would occur at the same rate as occurred between 30 June 2004 to 30 June 2005. The population was then interpolated to produce a quarterly series from March 1997 to June 2006.
- The national CPI from the March 1997 quarter to the June 2006 quarter, on a quarterly basis, provided by SNZ (and obtained via the Reserve Bank of New Zealand).
- The national CPI petrol price index, from the March 1997 quarter to the June 2006 quarter, on a quarterly basis, provided by SNZ. The petrol price index measures price change of 91 octane petrol, 96 octane petrol and petrol additive, which are then averaged across each quarter.

- The national GDP from the March 1997 quarter to the March 2006 quarter, on a quarterly basis, provided by SNZ. The ANZ Quarterly Economic Forecasts for June 2006 were used to forecast GDP for the June 2006 quarter.
- The national population estimates from the March 1997 quarter to the March 2006 quarter on a quarterly basis, provided by SNZ. The national population for the June 2006 was projected using past growth rates.[14]

C4.1.3 Data manipulation

The patronage data was manipulated to create quarterly variables for time series analysis of the period from March 1997 to June 2006:

- The first tranch of patronage and revenue data was transformed from weekly to quarterly data. Weeks of data were assigned to the quarter that encompassed them. Weeks of data that overlapped across quarters was assigned pro rata, based on the number of days of the week that fell into each quarter.
- The second tranch of patronage and revenue data was transformed from 4-weekly to quarterly data. Similarly to above, 4-week periods were assigned to the quarter that encompassed them, and overlapping 4-week periods were assigned on a pro rata basis.
- The quarterly patronage data was then adjusted to create two measures of patronage:
  - The ‘trips per day, per quarter’ measure was calculated by taking quarterly patronage and dividing by the number of days in each quarter to produce a trips per day figure.
  - The ‘trips per day, per quarter, per Wellington resident’ was calculated by taking the figure above and dividing by the estimated number of Wellington residents.

The other variables were also manipulated to create variables of interest:

- The revenue and patronage data was used to create an average nominal fare from March 1997 to December 1999. A separate average nominal fare was created for March 2000 because fares changed in this period. An average nominal fare was then calculated from June 2000 to March 2006.
- Both the average nominal fare and the petrol price index were deflated, using the CPI, to create average real fare and a real petrol price index.
- In addition, the real petrol price index was re-scaled so that the level of the real petrol price index in the June 2006 quarter was equivalent to the price of regular petrol as at 30 June 2006. This was done to enable easier interpretation of log-lin models.

C4.1.4 Model

A four-quarter annual differences model was estimated. The model was estimated in a similar fashion to the four-quarter annual differences model for petrol consumption;

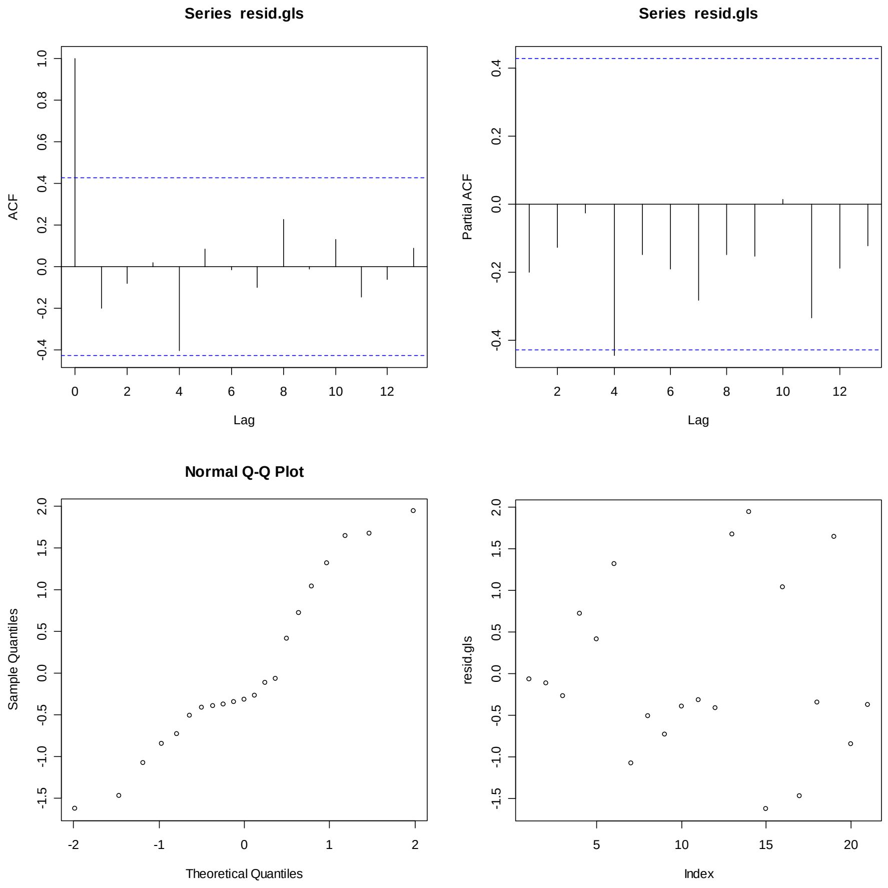
[14] The forecast growth from March 2006 to June 2006 was assumed to be the same as the average growth rate at the same time for the past three years (i.e. the average of growth from March 2003 to June 2003, from March 2004 to June 2004, and from March 2005 to June 2005 was calculated).

however, additional lags of petrol prices were included because these were found to be significant. The model was fitted using GLS.

C4.1.5 Results

A GLS model was estimated, with autocorrelation approximated using an AR(4) error structure:

```
Coefficients:
                        Value  Std.Error   t-value p-value
(Intercept)       -0.01194226 0.00634541 -1.882033  0.0794
petrol_index       0.16251779 0.02528016  6.428670  0.0000
lag1.petrol_index  0.21079527 0.02994290  7.039908  0.0000
lag2.petrol_index  0.17478838 0.01817554  9.616680  0.0000
lag3.petrol_index  0.06500649 0.02505406  2.594649  0.0203
gdp_capita         0.23274742 0.22922344  1.015374  0.3260


Augmented Dickey-Fuller Test
data:  resid.gls
Dickey-Fuller = -2.4375, Lag order = 2, p-value = 0.4057
alternative hypothesis: stationary
```



C4.1.6 Comment on model validity

- This model was not considered to be statistically robust. Most importantly, a risk of spurious regression could not be discounted. Also the Augmented Dickey-Fuller test shows that the possibility of non-stationarity in the residuals could not be dismissed.
- In addition, the model failed on other criteria for good econometric modelling.
- The ACF plot is satisfactory because it fails to detect autocorrelation. However the PACF plot suggests that residuals are negatively autocorrelated; this autocorrelation was not eliminated through the use of the GLS technique.
- The Q-Q plot shows that the residuals distributed in a non-normal manner, with too much weight distributed close to zero.
- The variance of the residuals appears to increase slightly with time in the plot of residuals against time, although this is not a definitive pattern.

C4.2 Christchurch bus patronage – Four-quarter annual differences

C4.2.1 Data sources

The data sources used for this analysis consisted of the following:

- Environment Canterbury patronage data.
- The national CPI from the September 1992 quarter to the June 2006 quarter, on a quarterly basis, provided by SNZ (and obtained via the Reserve Bank of New Zealand).
- The national CPI petrol price index, from the September 1992 quarter to the June 2006 quarter, on a quarterly basis, provided by SNZ. The petrol price index measures price change of 91 octane petrol, 96 octane petrol and petrol additive, which are then averaged across each quarter.
- The national GDP from the September 1992 quarter to the March 2006 quarter, on a quarterly basis, provided by SNZ. The ANZ Quarterly Economic Forecasts for June 2006 were used to forecast GDP for the June 2006 quarter.
- The national population estimates from the September 1992 quarter to the March 2006 quarter, on a quarterly basis, provided by SNZ. The national population for the June 2006 was projected using past growth rates.[15.]
- The Christchurch City (territorial authority) resident population estimates. These consisted of two series, both of which were obtained from the Christchurch City Council website[16] but were originally sourced from SNZ:

[15] The forecast growth from March 2006 to June 2006 was assumed to be the same as the average growth rate at the same time for the past three years (i.e. the average of growth from March 2003 to June 2003, from March 2004 to June 2004, and from March 2005 to June 2005 was calculated).

[16] *http://www.ccc.govt.nz/Christchurch/FactsStatsAndFigures/*

- The first series were estimates excluding census undercount adjustment, as at 30 June, from 1986 to 1995.
- The second series were estimates including undercount adjustment, as at 30 June, from 1996 to 2005. The population for 30 June 2006 was forecast based on the assumption that growth would occur at the same rate as occurred between 30 June 2004 to 30 June 2005.
- The two series could not, prima facie, be applied together because the inclusion of undercounts would have contributed to a spurious jump in population from 1995 to 1996. To redress this, it was assumed that the growth in population from 1995 to 1996 would have been equal to the average of growth from 1994 to 1995 and 1996 to 1997.

C4.2.2 Data manipulation

The quarterly patronage data was adjusted to create two measures of patronage:

- The ‘trips per day, per quarter’ measure was calculated by taking quarterly patronage and dividing by the number of days in each quarter to produce a trips per day figure.
- The ‘trips per day, per quarter, per Christchurch resident’ was calculated by taking this figure and dividing it by the estimated number of Christchurch residents.

Other variables were also manipulated to create variables of interest:

- The revenue and patronage data were used to create an average nominal fare from September 1992 to December 1999. A separate average nominal fare was created for March 2000 because fares changed during this period. An average nominal fare was then calculated from June 2000 to March 2006.
- Both the average nominal fare and the petrol price index were deflated, using the CPI, to create average real fare and a real petrol price index.
- In addition, the real petrol price index was re-scaled so that the level of the real petrol price index in the June 2006 quarter was equivalent to the price of regular petrol as at 30 June 2006. This was done to enable easier interpretation of log-lin models.

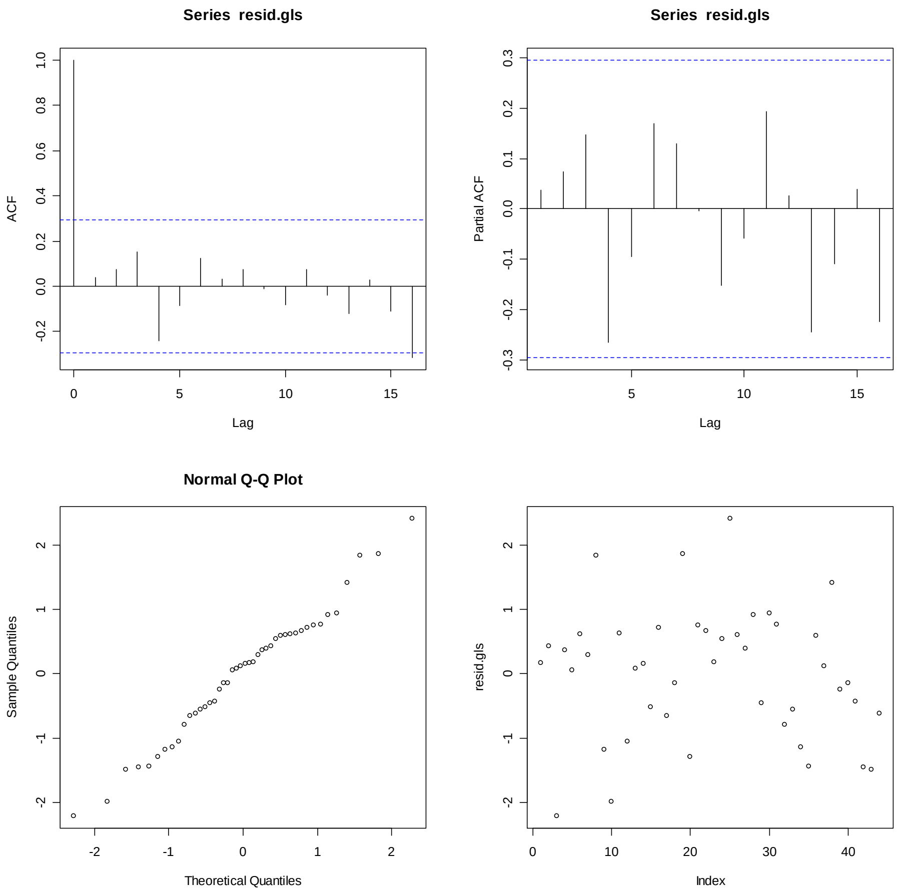
C4.2.3 Model

A four-quarter annual differences model was estimated. The model was estimated in a similar fashion to the four-quarter annual differences model for petrol consumption. However, additional lags of petrol prices were included because these were found to be significant. The model was fitted using GLS.

C4.2.4 Results

A GLS model was estimated, with autocorrelation approximated using an AR(4) error structure:

```
Coefficients:
                        Value Std.Error    t-value p-value
(Intercept)         0.0247903 0.0185769  1.3344662  0.1898
petrol_index       -0.0027489 0.0617919 -0.0444858  0.9647
lag1.petrol_index   0.1273856 0.0683897  1.8626421  0.0701
lag2.petrol_index   0.1318747 0.0644820  2.0451379  0.0476
gdp_capita          0.8902046 0.3870149  2.3001820  0.0269

Augmented Dickey-Fuller Test
data:  resid.gls
Dickey-Fuller = -3.072, Lag order = 3, p-value = 0.1494
alternative hypothesis: stationary
```



C4.2.5 Comment on model validity

The residuals were favourable (excluding the risk of non-stationarity discussed below). The ACF and PACF failed to detect autocorrelation. The Q-Q plot shows a straight line, consistent with normality. And the plot of residuals against time failed to exhibit any trends through time (as was desired).

The main problem was that the possibility of spurious estimates could not be disregarded; also the possibility of non-stationarity in the residuals could not be rejected by the Augmented Dickey-Fuller Test (although the risk was not as high as observed in the Wellington patronage analysis).

In addition, all the estimates are insignificant, except for GDP per capita and the last lag of the petrol price index. This suggests that the model is failing to explain much, and this failure is perhaps due to the omission of important variables (i.e. improvements in route services in Christchurch over the time period being studied).

Appendix D: Review of previous research

Summaries of the literature pertaining to research on effects of transport fuel price changes that have been published are provided in the following tables:

D1 Petrol consumption elasticities
D2 Traffic volume elasticities
D3 Public transport cross-elasticities

D1 Petrol consumption elasticities

Table D1.1 New Zealand evidence for petrol consumption elasticities.

City/Country	Dataset	Elasticity			Comments	Source
		Short Run	Long Run	Not Stated or Established		
New Zealand	Time series analysis: 1989 to 2001, quarterly data Petrol price index Petrol consumption	-0.195	-0.065		The researcher followed a robust procedure: a co-integrating relationship in the data was identified to justify the estimation of a long-run elasticity for petrol consumption. An error correction model was used to establish a short-run elasticity for petrol. The results of this empirical research are unusual, compared to most international research, because the short-run elasticity is estimated to be larger than the long-run elasticity. Note that the length of the time series is relatively short.	Barns (2002)
New Zealand	Time series analysis: 1969-79 Petrol consumption	-0.11	-0.14		Cited in Travers Morgan (1993).	Hughes (1980)
New Zealand	Nature of analysis not established Petrol consumption	-0.034	-0.074		Elasticities were developed for an energy demand forecasting study, using a method not established by this report. Cited in Collins (1993). Also cited in Lewthwaite & Douglas (1992).	Ministry of Commerce (1991)
New Zealand	Time series analysis Petrol consumption	-0.065	-0.188		The data was fitted with a partial adjusted model.	MED (2000)
New Zealand	Time series analysis: 1961-81 Petrol consumption	-0.131	-0.160		Cited	Waikato University (1982)
New Zealand	Nature of analysis not established			-0.26	Cited in Pickford & Wheeler (2001).	Baas, Hughes & Treloar (1982)
New Zealand	Nature of analysis not established			-0.2	Cited in Pickford & Wheeler (2001).	Miller & Crowley (1989)

Table D1.1 New Zealand evidence for petrol consumption elasticities.

City / Country	Dataset	Elasticity			Comments	Source
		Short Run	Long Run	Not Stated or Established		
New Zealand	Simple analysis of price shock: 1990			-0.2*	The researchers noted that a rise in price from 92 cents to 109 cents caused consumption to remain static when it would otherwise have been expected to grow by 4%. On this basis they deduce an elasticity of -0.2. However, this report notes that some of the impact of the price shock on consumption may have also have been indirect, via a dampening of GDP. * This elasticity represents a log-lin relationship (i.e. the impact of a 1 cent price rise on the percentage growth in consumption) but since the price is approximately 100 cents this can be interpreted as a similar unit to the other elasticities in this table.	WCS (1991)
New Zealand	Simple analysis of price shock: 1971-1976 Petrol consumption			-0.105	Cited in Collins (1993). A simple demand model was fitted to explain the impact of the 50% rise in real petrol prices, between June 1971 and March 1976.	NZERDC (1977)

Table D1.2 Australian evidence for petrol consumption elasticities.

City / Country	Dataset	Elasticity			Comments	Source
		Short Run	Long Run	Not Stated or Established		
Australia	Time series analysis:1980-93 Transport energy index Diesel and petrol sold by Shell for road transport	-0.02	-0.13		The research follows a robust econometric approach: a cointegrating relationship is established in the time series data before the long-run energy price elasticity is estimated. The long-run estimate of -0.12 is stated in the text of the report, but the empirical output suggests -0.13. The short-run relationship was estimated using an error-correction model. The error-correction model included lags of the dependent variable. The short-run estimate was insignificant. Interestingly, total transport industry output is also incorporated as an explanatory variable. Also, it is important to note that the dependent variable includes both petrol *and* diesel.	Samimi (1995)
Australia	Time series analysis from 1955 to 1976 Petrol prices Petrol consumption *per capita*			OLS: -0.02 to -0.08 C-P: -0.05 to -0.08	A regression model is fitted using both OLS and a Cooley-Prescott model. The researchers conclude that the short-run elasticity is at most -0.08.	Schou & Johnson (1979)
Australia	Time series analysis from 1960 to 1985 Petrol price Petrol consumption	-0.05	-0.18		This research was reasonably statistically robust because lagged terms were included and the model was tested for autocorrelation, both of which reduce the risk of a spurious estimate. Also, a range of models were fitted and all produced similar estimates (at around -0.1 to -0.2). A lagged depended model was fitted to produce both short-run and long-run estimates. A Durbin-h test was employed and autocorrelation was not detected. The researchers also explored a polynomial distributed lag (PDL) model and estimated a long-run of about -0.2. An inverted lag (INV2) model was also fitted and this estimated a long-run of about -0.1.	Sterner, Dahl & Franzen (1992)

Table D1.2 Australian evidence for petrol consumption elasticities.

City / Country	Dataset	Elasticity			Comments	Source
		Short Run	Long Run	Not Stated or Established		
Australia and all states	Time series analysis: 1958 to 1981 Petrol prices Petrol consumption	NSW: -0.09	-0.38		The research appears to have fitted partial adjustment models. The research indicated large differences between states; for example, Western Australia and Tasmania were relatively more elastic. These differences were explained to be due perhaps to differences in the responses of rural traffic. The same researcher produced similar estimates in Donnelly (1981). These are not included here on the basis that they were probably superseded by the Donnelly (1984) research. The Australian estimates denoted "*" represent a weighted average of state results. The Australian estimates denoted "**" represent the results of a single national equation estimation. Cited in Luk & Hepburn (1993).	Donnelly (1984)
		VIC: -0.09	-0.38			
		QLD: -0.09	-0.39			
		SA: -0.16	-0.46			
		WA: -0.16	-1.03			
		TAS: -0.16	-1.03			
		AUS*: -0.10	-0.42			
		AUS**: -0.12	-0.67			
Australia	Time-series analysis: unspecified - 1974	-0.11	-0.22		Cited in Hensher & Young (1991).	Brain & Schuyers (1981)
Australia	Unestablished nature of analysis	-0.03	-0.07		The research indicated that both urban and non-urban travel are affected to the same extent by price changes. Cited in Travers Morgan (1980).	Filmer & Mannion (1979)
Australia	Time-series analysis of ABARE data: 1976-88 Petrol prices Petrol consumption			-0.66	The ABARE model data was used directly to estimate a fuel price elasticity of -0.25. The ABARE model data from 1976 to 1988 was used to estimate a fleet fuel elasticity of 0.09. This was combined with estimates of the vehicle price use elasticity (-0.26) and vehicle fleet elasticity (-0.31) to produce an overall estimate of -0.66. The researchers conclude that there is strong evidence that the (presumably long-run) petrol price fuel demand elasticity is in -0.54 to -0.71 range.	Hensher & Young (1991)

Table D1.2 Australian evidence for petrol consumption elasticities.

City/Country	Dataset	Elasticity			Comments	Source
		Short Run	Long Run	Not Stated or Established		
Australia	Analysis of a household survey in 2000 Household petrol consumption Petrol prices	Unleaded: -0.04 Leaded: -0.06			This analysis is derived from a CATI survey of 1400 households across Australian states (weighted to represent Australia). The survey asked respondents to compare fuel expenditure this year with that for the expenditure last year. Using stated expenditure patterns and observed price changes, elasticities were estimated. These elasticities appear to be underestimates because households that decreased consumption appear to have been excluded. Nevertheless, this approach is very robust and is a useful contribution to understanding of elasticities in Australia. Note that the elasticity represents only the short-run effect because the survey asked respondents about the impact only over the past year. Also, note that these elasticities represent the effects of petrol prices *on household consumption*, not general consumption of transport fuels.	Harding (2001)

Table D1.3 International evidence for petrol consumption elasticities.

City/Country	Study Type and Period	Elasticity		Comments	Source
		Short Run	Long Run		
All countries	Meta-analysis Petrol and diesel consumption	-0.25	-0.6	Hanly et al. (2002) & Goodwin et al. (2004) conducted a meta-analysis of (both petrol and diesel) fuel price elasticities, and estimated that: - the short-run fuel price elasticity is -0.25; - the long-run elasticity is around -0.6.	Hanly, Dargay & Goodwin (2002) Goodwin, Dargay & Hanly (2004)
All countries	Literature review Petrol consumption	-0.2 to -0.3	-0.6 to -0.8	Graham & Glaister (2004, 2002) surveyed the international demand literature, with the intention of assessing the magnitude of (petrol only) fuel demand elasticities as reported in the literature, and: - concluded that the average fuel-price elasticity is in the range of -0.2 to -0.3; - reported that long-run (petrol only) fuel price elasticity estimates typically fall in the -0.6 to -0.8 band. They also reviewed a range of *cointegration models*; most of these models produce short-run estimates less than those generally observed in the literature: and in the range -0.21 to -0.37.	Graham & Glaister (2004, 2002)
All countries	Literature review Petrol consumption	-0.25	-0.58	Espey (1998) carried out a meta-analysis of the literature, and estimated that: - the short-run (petrol only) fuel-price elasticity was -0.25 on average, with a median elasticity of -0.23; - the long-run (petrol only) fuel-price elasticity was -0.58 on average, with a median elasticity of -0.43.	Espey (1998)

Table D1.3 International evidence for petrol consumption elasticities.

<table>
<tr><th rowspan="2">City/Country</th><th rowspan="2">Study Type and Period</th><th colspan="2">Elasticity</th><th rowspan="2">Comments</th><th rowspan="2">Source</th></tr>
<tr><th>Short Run</th><th>Long Run</th></tr>
<tr><td>21 OECD countries</td><td>Time series analysis: 1960-1985</td><td>-0.20 to -0.25</td><td>-0.24</td><td>Sterner et al. (1992) use a range of models to estimate petrol-price elasticities for 21 OECD counties, and found:
- Short-run estimates that are similar to those observed by others, in that:
o Partial adjustment models produced estimated one-year short-run elasticities ranging from -0.57 to +0.05 but the average across all countries was -0.24.
o Short-run estimates were similar when they fitted polynomial distributed lag models (-0.20) and inverted lag models (-0.25, -0.21).
- Long-run estimates that are similar to those observed by others, in that:
o Partial adjustment models produced average long-run elasticity of -0.79.
o Polynomial distributed lag models produced an average estimate of -1.0 and inverted-v models produced an average estimate of -0.6.</td><td>Sterner, Dahl & Franzen (1992)</td></tr>
</table>

Table D1.4 International evidence for impacts of time and petrol prices on petrol price elasticities.

City/Country	Study Type and Period	General Finding		Comments	Source
		Time	Petrol Prices		
All countries	Meta-analysis Petrol and diesel consumption		Higher during period of high prices	Hanly et al. (2002) found little evidence that elasticities change over time. The only exception was the higher price elasticities during the period of high prices following 1974. This suggests that price is a stronger driver of elasticities than trends over time.	Hanly et al. (2002), Goodwin et al. (2004)
UK	Time series analysis: 1960-73 1974-87 1988-00	Increasing over time		Hanly et al. (2002) use UK data to explore some of the findings from their literature review. They break the data down into periods (1960-73, 1974-87, 1988-00), and find some evidence of an increasing fuel-price elasticity (and an increasing VKT elasticity) but no evidence that it is decreasing.	Hanly et al. (2002), Goodwin et al. (2004)
OECD	Time series analysis	Increasing over time		Hanly et al. (2002) report that Dahl & Sterner (1991) examined successively extended tranches of the same dataset and his estimates suggested that the long-run elasticity of fuel consumption increased in successive periods.	Dahl & Sterner (1991)
US	Time series analysis: 1950-77 1978-94	Decreasing over time		Schimek (1997) broke US annual time series data into two periods: - from 1950 to 1977 he found that the short-run and long-run elasticities were, respectively, -0.18 and -0.87; - but from 1978 to 1994 the short-run and long-run elasticities were -0.13 to -0.73.	Schimek (1997)

D2 Traffic volume elasticities

Table D2.1 Australian evidence for vehicle traffic (or mode-choice) elasticities.

City/Country	Study Type and Period	Elasticity			Comments	Source
		Short Run	Long Run	Not Stated or Established		
Sydney, Australia	Discrete choice modelling of trip survey data from 1981 Vehicle operating costs Mode-choice			-0.04	The researchers combined data from a 1981 Sydney Regional Travel Survey with data on alternative modes (highway and transit) available in the Sydney region but not taken. The researchers used the data to predict the impact of explanatory variables on mode-choice.	Madan & Groenhout (1987)
Australia	Time series analysis: 1961-81 Petrol costs Vehicle kilometres driven			-0.04	Cited in Luk & Hepburn (1993)	Saad, Dao, Gerhardy & Biggs (1983)

Table D2.1 Australian evidence for vehicle traffic (or mode-choice) elasticities.

City/Country	Study Type and Period	Elasticity				Comments	Source
		Short Run	Long Run		Not Stated or Established		
Sydney, Australia	Cross-sectional analysis of survey data from 1981-82 Fuel costs per vehicle Vehicle kilometres driven	OLS: -0.24 2SLS: -0.09 3SLS: -0.10	OLS: -0.31 2SLS: -0.22 3SLS: -0.26			The models use data from a 1981-82 sample of 1434 Sydney households. The model estimates the impact of fuel costs per vehicle on contemporaneous kilometres driven (i.e. short-run) and long-run kilometres driven (i.e. long-run). The fuel-cost per vehicle should not be misinterpreted as necessarily representing the general cost of petrol: this represents the cost per km for each household and could perhaps be interpreted as a measure of vehicle efficiency. A number of regression model formulations are tested, OLS, 2SLS and 3SLS, all the reported estimates were statistically significant.	Hensher & Smith (1986)
Sydney	Regression analyses on household panel data, Sydney area, 1981-85 Fuel cost per vehicle Vehicle kilometres driven	1st wave -0.45 -0.35 -0.30 -0.10	1st wave -0.22 -0.30 -0.52 -0.26	4th wave -0.28 -0.34 -0.39		The figures represent households with 1, 2, 3 and 4+ vehicles per household, respectively. The figures provided are cited in Luk & Hepburn (1993). They focused on studies undertaken by Hensher and colleagues during the 1980s. The exact source of, in particular, the 4th-wave panel data could not be ascertained. The paper by Hensher et al. (1990) is cited but this paper appears to cover only the first wave of panel data.	Hensher, Milthorpe & Smith (1990)

Table D2.1 Australian evidence for vehicle traffic (or mode-choice) elasticities.

City/Country	Study Type and Period	Elasticity			Comments	Source
		Short Run	Long Run	Not Stated or Established		
Sydney, Australia	Survey of household experiences and expectations, as at 1980 Petrol cost Mode-choice				Survey results of 224 Sydney households found that about 21% 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)
Sydney, Australia	Cross-sectional analysis: survey data from 1981-82 Unit fuel cost for each household Total kilometres driven			1-3 vehicle households: -0.22 to -0.39 4 vehicle households: -0.06 to -0.14	A discrete choice model is used to predict the impact of explanatory variables on kilometres recorded by survey respondents. The model uses data from a 1981-82 sample of 1434 Sydney households. The unit fuel-cost per vehicle should not be misinterpreted as necessarily representing the general cost of petrol: this represents the cost per km for each household and is perhaps best described as a measure of vehicle efficiency.	Hensher, Milthorpe & Smith (1990)

Table D2.2 International evidence for vehicle traffic (or mode-choice) elasticities.

City / Country	Study Type and Period	Elasticity			Comments	Source
		Short Run	Long Run	Not Stated or Established		
International	International Review	-0.16	-0.33		The elasticities presented here represent the average of a number of international studies. Cross-section studies produced a similar estimate for the long-run effect: -0.29. Goodwin (1992) notes that the long-run elasticities (for both petrol consumption and vehicle traffic) are approximately twice the short-run. He notes that this seems plausible, especially in light of other empirical evidence suggesting that vehicle fleet sizes are responsive to petrol prices.	Goodwin (1992)
European Countries	European Review	-0.16	-0.26		The authors report on an extensive review of European studies, covering 12 European Countries. The elasticities shown here are represent the impact on total traffic. Commuting traffic elasticities were lower: -0.12 in the short-run and -0.23 in the long-run.	TRACE (1998) / de Jong & Gunn (2001)
Graham & Glaister (2002, 2004)	International Review	-0.15	-0.31		Graham & Glaister (2002) conclude the elasticities presented here, based on a review of the literature, and that with respect to traffic they are lower than the elasticities with respect to petrol consumption.	Graham & Glaister (2002, 2004)
International	International Review	-0.10	-0.29		The elasticities presented here represent the average of a number of international studies (dominated mostly or entirely by partial adjustment models). Again, cross-section studies produced a similar estimate for the long-run effect: -0.31.	Goodwin, Dargay & Hanly (2004)

D3 Public transport cross-elasticities

Table D3.1 New Zealand evidence for public transport cross-elasticities.

City/Country	Study Type and Period	Elasticity			Comments	Source
		Short Run	Long Run	Not Stated or Established		
New Zealand for seven main centres: Auckland, Wellington, Christchurch, Dunedin, New Plymouth, Invercargill and Timaru	Time series analysis: 1959-89, annual data Petrol PT Patronage			average: +0.07	This 1990 research by Travers Morgan examined patronage trends across seven main centres. Both static regression models and differences models were fitted and both produced an average estimate of +0.07. This estimate was found to be insignificant. The differences model is quite robust and will produce a good estimate of at least the short-run effect (although it may not pick-up long-run effects). Furthermore, the estimates benefit from a high quality dataset with considerable length (30 years) and scope (seven main centres).	Travers Morgan (1990) Wallis & Yates (1990)
New Zealand, Auckland	Time series analysis: 1967-78 Car operating costs PT patronage			+0.09	Cited in Travers Morgan (1990). Note that the research estimated a cross-elasticity with respect to total *car operating costs*.	Pringle (1979)

Table D3.1 New Zealand evidence for public transport cross-elasticities.

City/Country	Study Type and Period	Elasticity			Comments	Source
		Short Run	Long Run	Not Stated or Established		
New Zealand	Variety of analysis forms			Insignificant	Galt & Eyre (1985, 1987) examined the impact of car operating costs on buses and general public transport in New Zealand. They used both time series from 1987 to 1985 and also a before-and-after analysis. Both studies found that the impact of petrol prices was insignificant. However, another study by Galt & Eyre found that the cross-elasticity of car operating costs was +0.2 to +0.4. Cited in Travers Morgan (1990).	Galt & Eyre (1985, 1987)
New Zealand, Wellington and Hutt Valley	Time series analysis: 1998-2000, weekly			Wgtn Total +0.18 (CI +0.13 to +0.24) Wgtn Off-peak +0.11 (CI +0.05 to +0.17) Wgtn Peak +0.29 (CI +0.21 to +0.37) Hutt Valley +0.16 (CI 0.00 to +0.32)	BAH (2000) carried out a Wellington fares study for the Wellington City Council to explore the impacts of a 2000 fare-increase on bus patronage. As part of the fares study, they estimated petrol cross-elasticities.	Booz Allen Hamilton (2000)

Table D3.1 New Zealand evidence for public transport cross-elasticities.

City/Country	Study Type and Period	Elasticity			Comments	Source
		Short Run	Long Run	Not Stated or Established		
New Zealand, Christchurch	Simple analysis of impact of carless days in the 1979-80 period				Researchers analysed the 'before-and-after' impacts of carless cars. The results indicated reluctance to take public transport; of all the car trips that were avoided, only 10% were displaced to public transport – almost half preferred to convert to 'share another car'. Cited in Travers Morgan (1993).	Johnston, Elliot, Fletcher & Lander (1983)

Table D3.2 Australian evidence for public transport cross-elasticities.

City / Country	Study Type and Period	Elasticity			Comments	Source
		Short Run	Long Run	Not Stated or Established		
Australia, Sydney	Discrete choice modelling of trip survey data from 1981 Vehicle operating costs Mode-choice			+0.068	The researchers combined data from a 1981 Sydney Regional Travel Survey with data on alternative modes (highway and transit) available in the Sydney region but not taken. The researchers used the data to predict the impact of explanatory variables on mode-choice. However, the components of 'vehicle operating cost' are not specified in the paper. The estimate of +0.07, as reported by Luk & Hepburn (1993) was based on this research.	Madan & Groenhout (1987)
				Australia: +0.01 Melbourne: +0.005	Kinnear (1980) estimated the impact of private vehicle costs on public transport in Australia, and estimated that: - the cross-elasticity of Australian public transport, with respect to petrol price, was +0.01; - the cross-elasticity of Melbourne bus and tram transport, with respect to private vehicle costs, was +0.005. Kinnear also cited a 1964 home interview survey which was used to estimate a cross elasticity of Australian public transport, with respect to the petrol price, of +0.08.	Kinnear (1980)
Australia, Adelaide	Time series analysis: 1985-93, quarterly data Fuel cost PT patronage			Base Model: +0.44 Log Model: +0.35	This time-series analysis of Adelaide public transport employed both a linear model and a log model. The model structure was static and the R^2 was very high.	Willis (1994)
Australia					Holsman & Lonergan (1980) report on a survey of 224 Sydney households. The households were asked about the effects of recent fuel-price rises on their behaviour: only 2% of households reported 'greater use of public transport' as a major or secondary response to higher fuel prices. Most households reported 'less frequent use of car(s)' as a more common response.	Holsman & Lonergan (1980)

Table D3.2 Australian evidence for public transport cross-elasticities.

City/Country	Study Type and Period	Elasticity			Comments	Source
		Short Run	Long Run	Not Stated or Established		
Australia	Time series and panel data analysis: 1977 to 1989 Petrol price index			Insignificant and of incorrect sign	Gargett (1990) fitted a time-series model for public transport using aggregate Australian data. An additional model exploited time-series data on state-level public transport patronage. Both models found that the impact of the petrol price index was of the incorrect sign and insignificant.	Gargett (1990)
Australia, Sydney	Unspecified analysis Suburban rail network patronage Petrol price			+0.8	Cited in Gargett (1990).	Gallagher (1985)
Australia, Melbourne	Time series analysis: Tram patronage Motor costs index			The motor costs index had significant negative relationship in virtually all the models	Models were estimated for Melbourne and Preston tram services. Separate models were estimated for different categories of passenger (e.g. 'Adult 4 & 5 sections').	Singleton (1976)
Australia	Stated Preference survey			+0.20	This Stated Preference research states that a 25% increase in fuel prices would elicit a 5% increase in public transport patronage. This has been interpreted in this present report as equivalent to a +0.20 cross-elasticity.	DJA–Maunsell (1992)
Australia, Sydney	Joint Stated Preference and Revealed Preference	+0.17			This stated preference research focused only on peak commuters. Cited in Wallis (2004).	Taplin, Hensher & Smith (1999)

Table D3.2 Australian evidence for public transport cross-elasticities.

City/Country	Study Type and Period	Elasticity			Comments	Source
		Short Run	Long Run	Not Stated or Established		
Australia, Melbourne	Time series analysis: 1979-1996 Rail patronage			+0.70	The estimate produced by this research was statistically significant. Cited in Wallis (2004)	Booz Allen Hamilton (1999)
Australia, Melbourne	Time series analysis:			Heavy rail: +0.475 Train and bus: +0.217 Tram and bus are each negative and insignificant on their own	Forthcoming publication.	Currie & Phung (2006)

Table D3.3 International evidence for public transport cross-elasticities.

City/Country	Study Type and Period	Elasticity			Comments	Source
		Short Run	Long Run	Not Stated or Established		
UK	Derivation of cross-price estimates using own-price estimates			Intercity +0.094 Network South East +0.041 Regional Railways +0.091 London Underground +0.017 London Buses +0.020 Other local buses +0.013	Acutt & Dodgson (1996) derived estimates of petrol cross-price elasticities using a range of inputs: previously obtained estimates of own-price elasticities; expert estimates of diversion rates; and the ratio of average petrol costs to average fare costs. These were combined together to produce estimates of the cross-elasticity of demand with respect to petrol.	Acutt & Dodgson (1996)
France, Paris	Time series analysis: 1980 to 1996	Paris: +0.044 to +0.111 France: +0.059	Paris: +0.118 to +0.192 France: +0.093		Bresson et al. (2002) provide a range of estimates for oil-price cross elasticities of demand for public transport in Paris, for the 1980 to 1996 period. They estimated that the oil-price cross elasticity for Paris was +0.044 in the short-run and +0.118 in the long-run. They also analysed panel data for 62 urban areas (including Paris) across France, for a period from 1975 to 1995. They estimate that the oil price cross-elasticity for all these urban areas (using a shrinkage estimation approach) was +0.059 in the short-run and +0.093 in the long-run. When restricted to Paris only, the estimate was +0.111 in the short-run and +0.192 in the long-run.	Bresson, Madre & Pirotte (2002)

Table D3.3 International evidence for public transport cross-elasticities.

City/Country	Study Type and Period	Elasticity			Comments	Source
		Short Run	Long Run	Not Stated or Established		
Various				+0.34	Goodwin (1992) reviewed three studies: Bland (1984), Doi & Allen (1986), and Wang & Skinner (1984). These three studies produced five estimates, which ranged from +0.08 to +0.8. The average estimate was +0.34: - The Bland (1984) estimates were based on the LUTE model, which mainly calibrated from UK National Travel Survey (NTS) data. The model produced estimates of bus-use with respect to fuel price of +0.2 to +0.5. - The Doi & Allen (1986) estimates were produced using time-series analysis of monthly transit ridership between 1978 and 1984. The elasticity of ridership with respect to petrol price was +0.11. - The Wang & Skinner (1984) estimates were produced using time series analysis of monthly ridership for seven US transit authorities. The time series varied in length, but all were encompassed by a 1970 to 1981 time period. The estimates ranged from +0.08 to +0.80.	Goodwin (1992)
Germany	TBA			+0.07	Storchman (2001) developed an econometric model, consisting of 121 equations, to model public transport in Germany. The model produces an overall cross-price elasticity of +0.07. Storchman argues that high price elasticities of leisure travel by car are not accompanied by comparable cross-price elasticities for public transport; he claims that people who use their cars for leisure purposes virtually never switch to public transport. The complexity of the model means that it is not presented in a transparent manner, and is hence cannot be assessed on quality.	Storchman (2001)
					Algers et al. (1995). Bovy et al. (1991). Wang & Skinner (1984).	
US, Chicago	Time series analysis: 1970-80, monthly data	+0.11	+0.18		Rose (1986) developed an ARIMA model for the Chicago Transit Authority (CTA) rail system.	Rose (1986)

Table D3.3 International evidence for public transport cross-elasticities.

City/Country	Study Type and Period	Elasticity			Comments	Source
		Short Run	Long Run	Not Stated or Established		
Various European countries	Literature review of TRACE research	+0.33	0.07		The authors describe the results of the European Commission-funded TRACE (1998) research. This research included a review of fuel-price cross-elasticities with respect to public transport trips. De Jong & Gunn (2000) note that the elasticity of some measure does not exist; elasticities vary with circumstances or 'contexts'. De Jong & Gunn compare the average estimates from European literature with the estimates from three extensive transport models.	de Jong & Gunn (2000)

Appendix E: References

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