Impacts of Petrol Prices on Consumption and Travel Demand - New Zealand Evidence

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1 Introduction

Over the period from December 2005 to July 2006, prevailing petrol prices in New Zealand rose from around $1.30/litre to around $1.80/litre, an increase approaching 40% Over that period, rising fuel prices has been one of the hottest topics in the New Zealand media. A sample of newspaper headlines illustrates some of the impacts of these rising prices through the transport sector and the wider economy:

- *"Petrol soars past high of $1.70"*
- *"Fuel rage grows as petrol price surges"*
- *"Fuel squeeze on transport fares"*
- *"The strain on our buses and trains"*
- *"Cash flow to Govt slows as drivers cut back"*
- *"Fuel costs hit sales of new 4WD cars"*
- *"Revolution in car values turns on fuel prices"*
- *"Higher fuel costs cause families more pain than mortgages".*

Understanding of how the market is likely to respond to changes in fuel prices is crucial to many areas of government forecasting, policy development and funding in New Zealand (as in most other countries). Evidence on responses to fuel prices is important in the following areas:

- Forecasting of government taxation revenues, including revenues hypothecated to the Land Transport Fund (and hence available for expenditure on the transport system)
- Forecasting of economic growth, and hence the related setting of monetary policy
- Transport emissions forecasting, including the NZ Government's financial obligations under the Kyoto Protocol
- Forecasting of traffic growth trends, for use in road investment planning and evaluation. (Current NZ traffic forecasting practices are based primarily on a continuation of past traffic growth rates)
- Public transport planning, particularly in regard to future peak demand levels and hence rollingstock requirements.

Hitherto, a variety of approaches have been used in the NZ transport sector (and related sectors of government) to forecasting future transport fuel prices and the market response to these. Methods of forecasting responses have been based on a range of older NZ and international sources. In some cases where it might be thought that such forecasts might be important (eg. for deriving traffic growth trends), rather simplistic 'business-as-usual' methods have been applied.

The study reported here was designed to derive better information on market responses to transport fuel price changes in NZ. The study was commissioned and funded by Land Transport NZ, based on a concept and approach developed by Booz Allen Hamilton (NZ).

The study involved econometric analyses of the impacts of transport fuel (petrol/diesel) price changes on fuel consumption (petrol/diesel), traffic volumes (cars/trucks) and public transport patronage levels. This paper covers part only of the study, concerned with the impacts of petrol price changes on petrol consumption (period 1974-2006) and on car/light van traffic volumes (2002-2006). It focuses primarily on the price elasticity estimates obtained (in the short run and long run) and compares these with other elasticity evidence from NZ, Australia and internationally: from this appraisal, it suggests the most appropriate elasticity values for use for policy analyses purposes in NZ.

Section 2 of the paper summarises the study analyses and presents the resultant elasticity estimates. Section 3 then compares these estimates with other evidence from previous NZ, Australian and international studies. Section 4 draws together all the evidence and develops 'best estimate' elasticity values for use in NZ. It also highlights some unresolved issues and aspects for further research using the data set now available.

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 the paper does not discuss these methods in detail, Appendix A provides an overview of the methods used for the interested reader (further details are available in the study report).

2 Study analyses

2.1 Petrol consumption analyses

2.1.1 Source data

The analyses were all undertaken at a national level, using quarterly data, covering the period 1974 – March 2006. Table 1 presents a summary of the data sources used.

Table 1 Petrol consumption analyses – data sources

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)
Gross domestic product	NZ GDP series with interpolation of annual data prior to 1977 (SNZ, Victoria University)
Population	NZ Quarterly residential population estimates with interpolation of annual data prior to 1991.

Note: SNZ=Statistics New Zealand, MED=Ministry of Economic Development

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

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

Figure 1 shows how petrol prices 'mirror' petrol consumption over the period 1978-2006. To improve clarity, the data has been smoothed with a four-quarter moving average:

Figure 2 provides an alternative presentation of the data from Figure 1: for each quarterly period, it shows the percentage change in petrol price and petrol consumption relative to the same quarter 12 months earlier. While there is considerable scatter of results, again the correlation between price changes and consumption changes is evident.

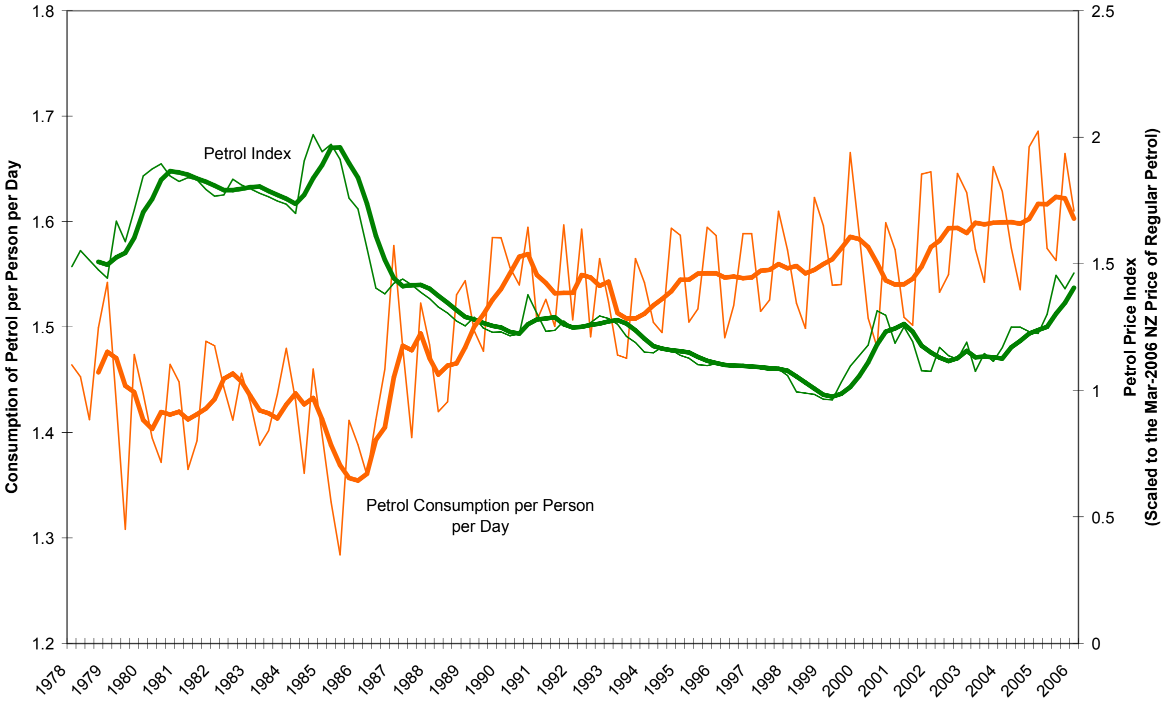

Figure 1 Trends in petrol prices and petrol consumption (1978-2006)

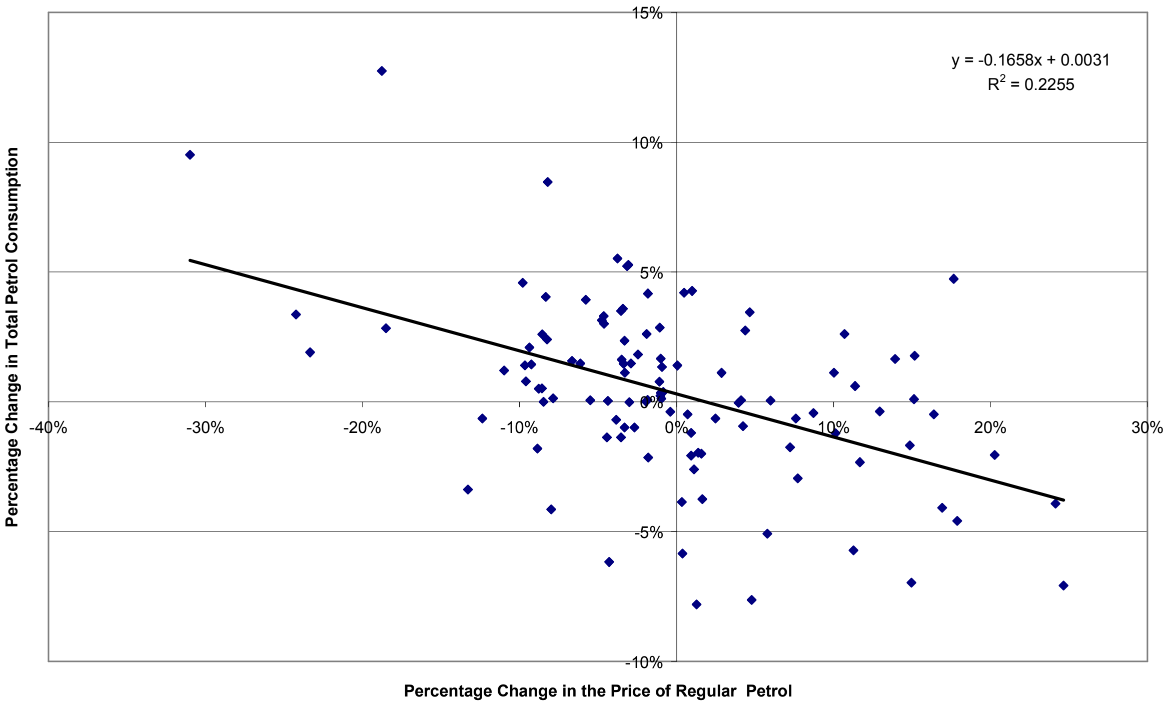

Figure 2 Short-run relationship between petrol prices and consumption (1978 to 2006): quarterly data, year-on-year changes

2.1.2 Models

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

Five model types were tested in this case, as shown in Table 2 (in broadly descending order of model quality): the table also provides notes on some of the issues and deficiencies associated with each model. Further description of the various model types is provided in Appendix A.

Table 2 Petrol consumption models and elasticity results

Model Type	Short Run Effect (0-1 year)	Medium Run Effect (0-2 years)	Long Run Effect (3+ years)	Notes
A. Quarterly annual differences model (GLS) (1978-2006)	0.14***	0.19	As MR	‣ These two model types likely to be most reliable, as use 112 data points ‣ Ordinary leased squares (OLS) model produces unbiased estimates, but unreliable error margins due to auto-correlation of residuals. Therefore the generalised leased squares (GLS) model is preferred.
B. Quarterly annual differences model (OLS) (1978-2006)	0.17***	0.23	As MR	
C. Quarter-to-quarter differences model (1978-2006)	0.12 0.11 0.04 0.27	0.27	As MR	‣ The 3 SR estimates relate to first quarter effect (unlagged), second quarter effect and third/fourth quarter effects (lagged) ‣ Model requires inclusion of seasonal dummies ‣ Model should be regarded with caution, as results inconsistent with other models.
D. Annual differences model (1974-2005)	0.13*	0.24	As MR	‣ Model produces unbiased estimates, but is less trustworthy as limited to 30 data points.
E. Annual partial adjustment model (1974-2005)	0.11**	0.14	0.17	‣ Model should be regarded with considerable caution, as detailed analysis indicates a high risk of spurious relationships between trending variables.

Notes: Significance of results denoted ***0.1%, **1%, *5%, ‘10%
(significance levels not calculated for medium-run effects).

2.1.3 Results and comments

Table 2 shows the best estimates for petrol consumption price elasticity derived from each model over three different timescales:

- Within one year (‘short’ run)
- Within two years (‘medium’ run, includes short-run effects)
- After three or more years (‘long’ run, includes medium-run effects).

(Note that all elasticities quoted in this paper are negative, but for simplicity the negative signs have been omitted throughout.)

Taking account of the quality of the various models, we would draw out the following findings relating to consumption elasticities:

- There is a considerable degree of consistency across the different model results (despite reasonably wide margins of error in most cases).
- The first year elasticity values are around 0.14 (four of the five models give best estimates in the range 0.11 to 0.17).
- 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.
- The cumulative elasticity estimates after 2 years are around 0.20, with further changes beyond 2 years being very small and difficult to detect with any confidence.

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

- In the short run (within 1 year), a fall of about 1.4%
- In the medium run (within 2 years), a fall of about 2.0%.

Elasticities of petrol consumption/capita with respect to GDP/capita changes were also estimated from the models. In most cases, significant estimates were obtained, with average elasticities around 0.3 (ie. a 10% GDP/capita increase would increase petrol consumption/capita by around 3%: this impact will include both a 'car ownership effect' and an income effect.

2.2 Traffic volume analyses

2.2.1 Source data

The analyses were undertaken at a national level (refer below), using weekly data, covering the period 1 January 2002 – 18 June 2006 (4.5 years). Table 3 presents a summary of the data sources used.

Table 3 Traffic volume analyses – data sources

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 (Ministry of Economic Development).
Gross domestic product	NZ GDP quarterly series, interpolated to provide weekly data (SNZ).
Population	NZ Quarterly residential population estimates, interpolated to provide weekly data.

The aggregations of traffic count data on state highways throughout New Zealand were used, as a proxy variable for total traffic volumes or 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)
- 4 vehicle length classes (the shortest length class, up to 5.5 metres, was taken as a proxy for petrol vehicles; the other three categories accounted largely for trucks, predominantly diesel vehicles).

The full data set was used to derive traffic volume summaries for each site, for the shortest vehicle length class, by week and by peak v off-peak periods ('peak' was taken as 0700-0900, 1600-1800). The results were then grouped into urban v rural areas, and total aggregated weekly traffic volumes for the shortest vehicle class were derived for four groups: Rural, Urban Peak, Urban Off-Peak, Total All. This process involved considerable data manipulations to adjust for situations with missing data.

For analysis purposes, the following weekly variables were used:

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

Samples of the data are shown in Figures 3, 4 and 5:

- Figure 3 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.

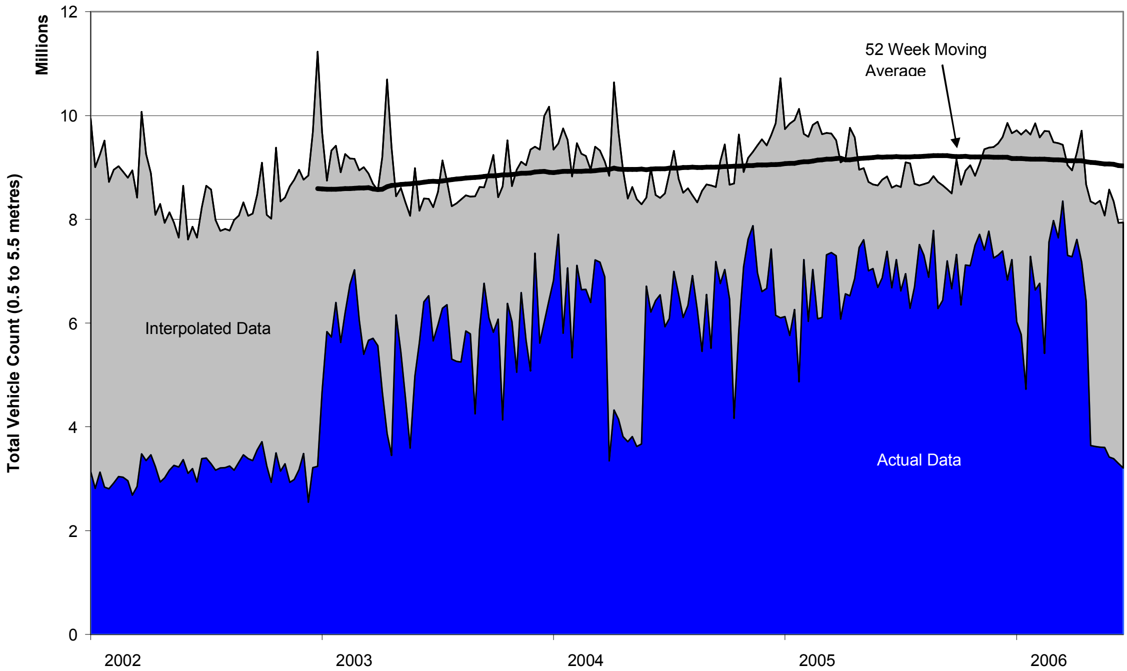

Figure 3 Actual and interpolated total vehicle counts (vehicles up to 5.5 metre lengths), 2002-06

- Figure 4 gives the year-on-year changes (smoothed using a 13 week moving average basis) in 'car' traffic volumes (per capita), petrol prices and GDP/capita. Throughout the period until mid-2005, car traffic volumes/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 a year-on-year decline of 4%-5%. There is a clear correlation between traffic volumes and petrol prices – refer in particular the periods around July 2003, April 2005 and since October 2005. Any correlation between traffic volumes and GDP/capita is not obvious here.

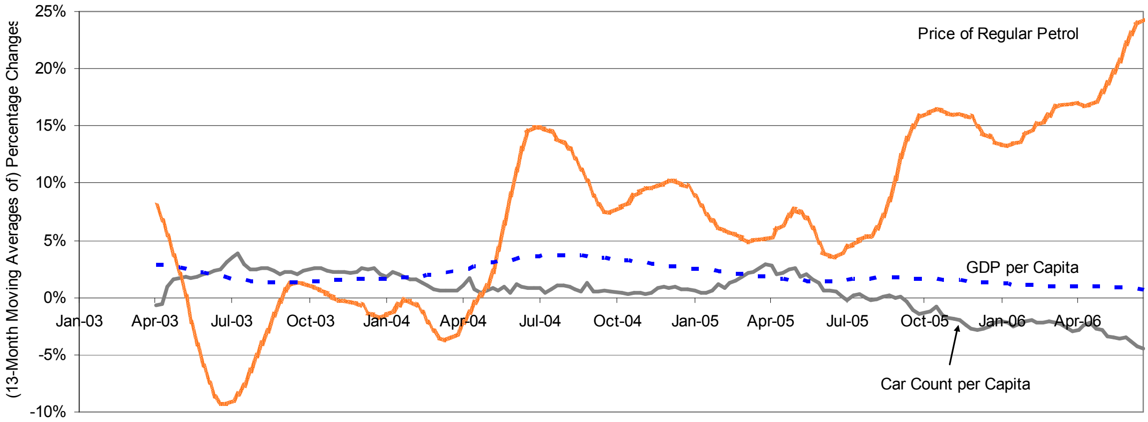

Figure 4 Yearly changes in VKT per capita, petrol price and GDP/capita

- Figure 5 gives an alternative view, using the same data, of the relationship between year-on-year changes in car traffic volumes and petrol prices. The best fit line to this data indicates an ‘underlying’ traffic volume growth of around 1.5-2% pa with constant petrol prices, but changing to zero growth when petrol prices increase at around 10% pa (real terms).

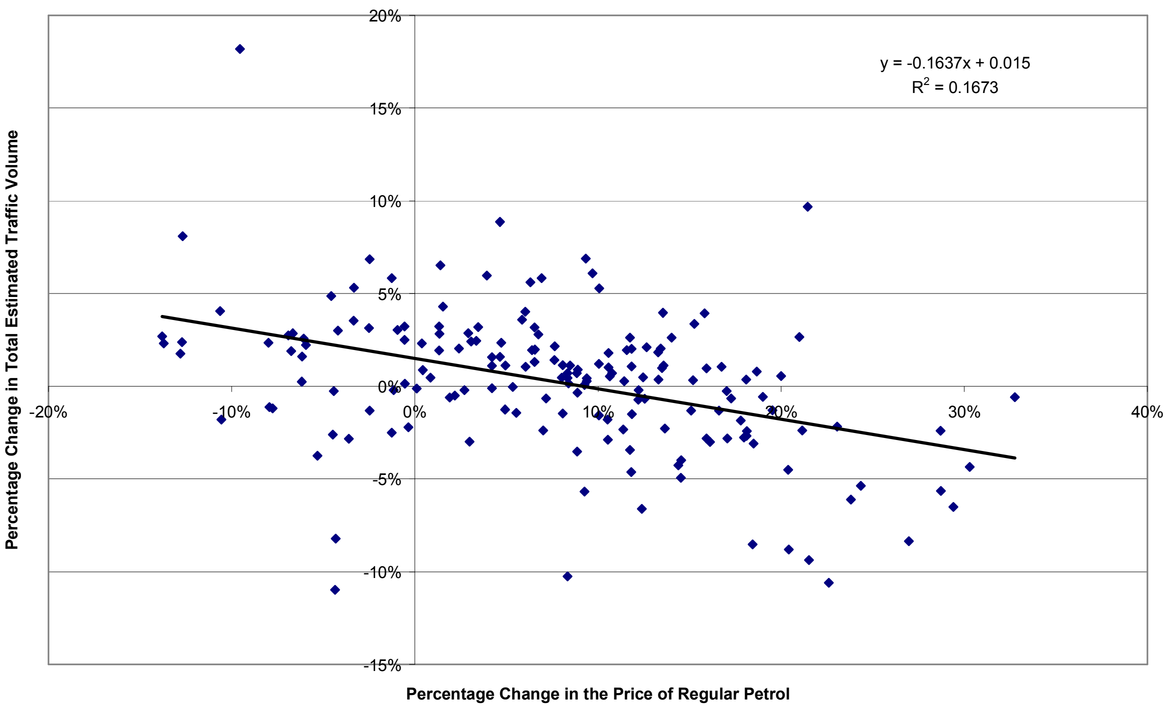

Figure 5 Short-run relationship between petrol prices and traffic volumes (January 2002 to June 2006)

2.2.2 Models

For modelling purposes, the three variables noted above were used, 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.

2.2.3 Results and comments

Table 4 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 4 Car traffic volume models and elasticity results[1]

Data Set	Short Run Effect (0-1 year)	Medium Run Effect (0-2 years)	Diagnostic Analysis Notes
Total All	0.23*** (± 0.11)	0.35	▸ Some autocorrelation at high lags ▸ Some non-normality in residuals ▸ Unusually high variance at beginning of time series
Rural All	0.24*** (± 0.11)	0.36	▸ Minor autocorrelation ▸ Normality in residuals ▸ Roughly constant variance through time
Urban Off-Peak All	0.28*** (± 0.12)	0.39	▸ Some autocorrelation at a high lag ▸ Non-normality in residuals ▸ Unusually high variance at beginning of time series
Urban Peak All	0.08 (± 0.12)	0.26	▸ Minor autocorrelation ▸ Normality in residuals (except for one outlier) ▸ Roughly constant variance through time
Urban Peak – Limited Sites[2]	0.11** (± 0.08)	0.29	▸ Minor autocorrelation ▸ Normality in residuals ▸ Constant variance through time

Notes: (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).
(2) This data set 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.

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 (due to the more desirable patterns of their residuals). Having regard to this, we would draw out the following findings relating to traffic volume elasticities:

- The volume elasticities are very similar for Rural, Urban Off-Peak and Total sites at around 0.25 within one year, 0.35 to 0.40 within 2 years of price changes.

- These elasticities follow a similar pattern to the petrol consumption elasticities discussed earlier, in that most of the impact occurs within the first year and any further effects decline rapidly thereafter.
- The volume elasticities for Urban Peak are markedly lower, particularly in the short run: they are around 0.11 within one year, but approaching 0.30 within two years.
- The estimated medium-run elasticities (within two years) of around 0.3 to 0.4 are significantly higher than the consumption elasticities of around 0.2 to 0.25. (It should be noted that the consumption analyses cover a much longer time span than the traffic volume analyses, so differences in these sets of results are not surprising: this is discussed further in a later section).

These model estimates imply that the impacts of a 10% (real) rise in petrol prices on car traffic volumes would be:

- In the short-run (within one year), a fall of about 2.5% in rural and urban off-peak situations, but around half this in urban peak situations.
- In the medium-run (after two years), a fall of about 3.5%-4.0% in rural and urban off-peak situations, but under 3% in urban peak situations.

Estimates of the effects of petrol prices on car traffic volumes indicate that more than 50% of the impact of prices feeds through in the short-run. This is consistent with the estimated impacts of prices on petrol consumption, as noted earlier.

The effects of changes in GDP/capita on car traffic volumes were also estimated from the models, but were generally insignificant. However, the elasticity of total car traffic volumes with respect to GDP/capita was about 0.3: this is very consistent with the GDP/capita impact on petrol consumption noted earlier.

3 Comparisons with international evidence

3.1 Petrol consumption elasticities

3.1.1 New Zealand evidence

Table 5 summarises previous econometric studies on petrol consumption elasticities in new Zealand:

- Most short-run values are around 0.10 (range 0.03 to 0.13), and long-run values around 0.15 (range 0.07 to 0.19).
- The exception is 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.

It is notable that the estimates derived in our study (around 0.14 in the short-run and 0.2 in the medium-run) are at the high end of the range found from these previous NZ studies.

Table 5 Petrol consumption elasticities – previous New Zealand studies

Source	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

3.1.2 Australian evidence

Table 6 summarises econometric studies of petrol consumption elasticities in Australia:

- One of the most robust and transparent studies is that by Sterner, Dahl and Franzen (1992). They fitted a partial adjustment model to Australian data from 1960 to 1985 and employed valid tests for autocorrelation. They 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, Dahl and Franzen'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 under-estimate the total impact, but is still more robust than many time-series estimates.
- Examining the Australian data overall, the short-run values appear to centre around 0.1 (range 0.02 to 0.12). This figure is very consistent with the estimate from Luk and Hepburn's (1993) review, and is also very similar to the range of values for NZ.
- The long-run values centre around 0.15 (range 0.07 to 0.22); this is again very similar to the NZ range (the exception is Donnelly's estimate of 0.67), but substantially lower than Luk and Hepburn's (1993) review conclusion.

From this evidence, there is nothing to indicate any significant differences between Australian and New Zealand consumption elasticities.

Table 6 Petrol consumption elasticities – Australian studies

Source	Short-run	Long-run	Not stated or established	Estimation method
Brain and Schuyers (1981)	0.11	0.22		Not established
Caddy (1985)			0.25	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 (Sydney only)
Samimi (1995)	0.02	0.13		Cointegration model
Schou & Johnson (1979)			0.02 to 0.08	Static models (OLS and Colley-Prescott)
Sterner, Dahl and Franzen (1992)	0.05	0.18		Partial adjustment model, but other models also fitted
Luk & Hepburn (1993)	c 0.10	0.40 to 0.70		Review of previous Australian evidence

3.1.3 International evidence

Sterner, Dahl and Franzen (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 7.

Table 7 Petrol consumption elasticities – international studies

Country/Region	Short-run	Long-run
Australia	0.05	0.18
US	0.18	1.00
Canada	0 25	1.07
UK	0.11	0.45
Europe - average - range	 0.28 0.05 to 0.57	 0.88 0.18 to 2.29

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, 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, Dargay & Goodwin (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 consumption elasticities between countries is far from straightforward. Sterner et al's data enable comparison of consumption elasticity estimates with petrol prices in different countries. The comparisons for the short-run elasticity are summarised in Figure 6: this suggests a relationship that is almost linear through the origin, ie. the short-run elasticity is almost directly proportional to the price level. This implies that the % consumption change is more closely related to the absolute price change rather than the % price change (a similar, but less strong, relationship appears to exist for the long-run elasticity). It appears that the absolute price differences between different countries may thus explain a substantial proportion of the elasticity differences between countries.

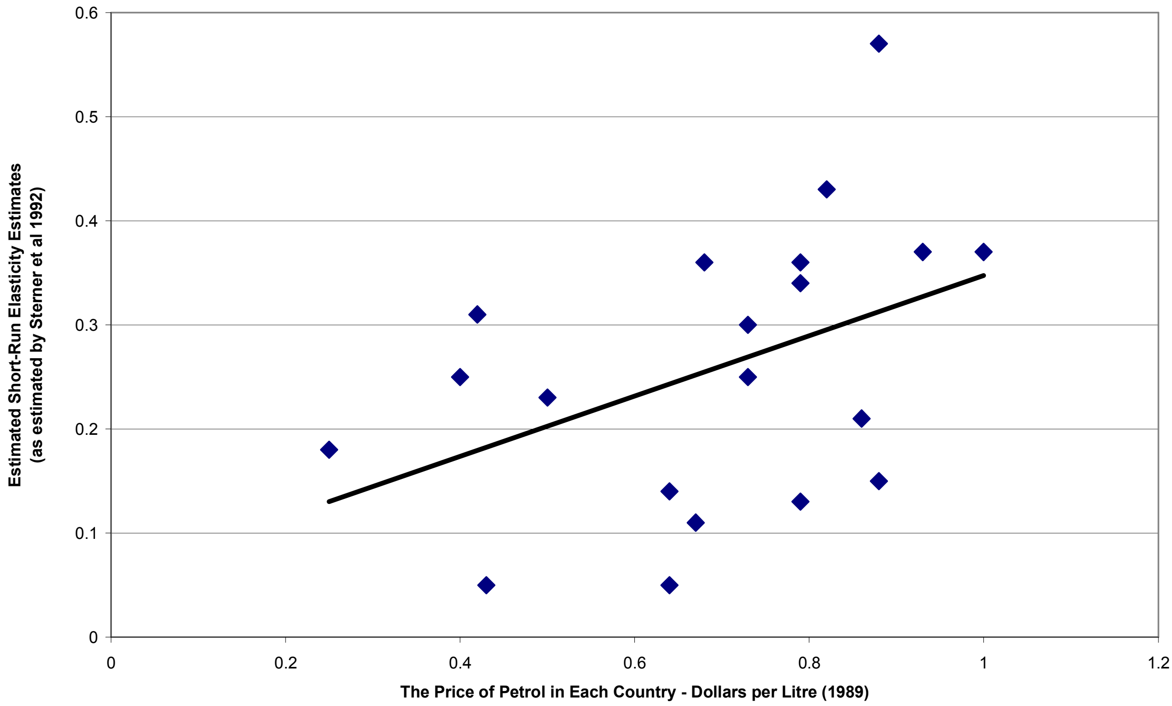

Figure 6 Relationship of short-run petrol consumption elasticity and price across different countries (Sterner et al, 1992)

Most analysts and commentators appear to agree that consumption elasticities are among the world's lowest in Australia/New Zealand, somewhat higher in US/Canada, and generally higher still in Europe – while noting a considerable range of responses across different European countries. However, it may well be that the differences between the Australian (and NZ) elasticities are considerably less than Sterner et al's estimates. As noted earlier, the weight of evidence indicates Australian and NZ short-run values centred around 0.1, with our study estimates for NZ centred around 0.14: this figure is much more comparable with the US and UK estimates, although still well below the European average. It may well be that our large factor behind the higher European figures is 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 NZ relative to US/Canada. This appears to be a field warranting further study.

3.2 Traffic volume elasticities

3.2.1 New Zealand evidence

This appears to be the first NZ study to attempt estimates of traffic volume elasticities with respect to petrol prices: no previous studies have been identified.

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 more recent studies since Luk and

Hepburn's (1993) review. This review relied largely on the work of Hensher and colleagues in the early 1980s: this work collected data from a four-wave panel of Sydney area households from 1981 onwards. Luk and 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

There is a reasonably significant body of international evidence on traffic volume (VKT) price elasticities, although this is not as substantial as for consumption elasticities. Table 8 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 a more 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.

3.2.4 Comparisons and conclusions

We would have anticipated (along with most other researchers in this field) a systematic relationship between VKT elasticities and consumption elasticities. In the short-run, we would expect VKT elasticities to be somewhat lower than consumption elasticities: 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 VKT elasticities would be expected to be substantially lower than consumption elasticities.

Table 8 Vehicle kilometre elasticities – international studies(1)

Source	Short-run	Long-run	Notes, Comments
Goodwin (1992)	0.16	0.32	▸ Major international review: values quoted are mean estimates.
TRACE (1998)/ de Jong and Gunn (2001)	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 under-estimate actual responses); long-run values allow for full range of behavioural responses.
Graham and 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 USA. ▸ Results relate to mean of dynamic estimation studies (static estimation studies gave mean of 0.31).

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

These expected relationships appear to be present in the international data. Comparing the results from Table 8 and Table 7, the short-run VKT elasticities (around 0.15) are somewhat below the average of the US, Canadian and European consumption elasticities (around 0.24); whereas the long-run VKT elasticities (around 0.3) are markedly lower than the corresponding averaged consumption elasticities (around 1.0). Goodwin's reviews of 1992 and 2004 gave a broadly similar pattern of results.

Luk and Hepburn's 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 NZ work do not exhibit this pattern. In the short-run (within 1 year), our best estimate VKT elasticity (Table 4) is around 0.20 to 0.25, while our petrol consumption elasticity (Table 2) is around 0.15. Similarly, in the medium-run (up to 2 years), our VKT elasticity is around 0.35, while our consumption elasticity is around 0.20. The reasons behind these apparently anomalous results are at this stage not fully clear, although we would suspect one major factor is the different data periods used for the two sets of analyses: the consumption analyses cover the period 1974-2006, while the VKT analyses cover the much shorter period 2002-2006. Our findings on VKT elasticities for the 2002-06 period might suggest that the consumption elasticities for this period are substantially higher (maybe around 0.3 in the short-run) than for the earlier period. Further statistical testing might confirm whether or not this is the case.

4 Overall conclusions and policy implications

4.1 What conclusions can be drawn?

Table 9 draws together and summarises all the evidence presented previously, providing VKT and petrol consumption elasticities from our NZ analyses, previous NZ analyses, Australian analyses and international analyses. Focusing particularly on the short-run results, our findings are that:

- In terms of VKT elasticities, our NZ estimates (based on recent data, 2002-06) are higher than typical Australian and international values.
- In terms of consumption elasticities, our NZ estimates (based on a long-term data series, 1974-2006) are on the high side of previous NZ and Australian studies, slightly lower than the US/Canadian estimates and substantially lower than the European average (but above the UK estimates).

Table 9 Summary of elasticity evidence

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

Goodwin et al (2003) 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 NZ traffic volume (VKT) effects are greater than these international averaged estimates; but that the NZ consumption effects are rather less than these international estimates. Our NZ results do cast some doubt on the view quite often expressed that NZ and Australian elasticities are among the world's lowest.

As noted earlier, the relationship between the VKT and consumption elasticities derived in our study is not as expected: the VKT elasticity would be expected to be lower, not higher, than the consumption elasticity. A major factor causing this anomaly may well be the different time periods involved in the two sets of analyses. We would hypothesise that one factor behind the relatively high VKT elasticity (over the period since 2002) may be the expectation that the price rises were likely to be part of an ongoing trend, rather than would rapidly reach a plateau or even decline. Another factor was that the more recent price rises came at a time of a slowing of economic growth, with speculation of an imminent recession (including falls in house prices).

One of the most interesting aspects of our NZ VKT elasticity results was the differences between urban peak, urban off-peak and rural responses (we are not aware of any other such disaggregated analyses in the international literature). All indications (Table 4) are that the urban peak elasticity is substantially lower than the urban off-peak and rural elasticities: 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 estimate' elasticities for policy analysis purposes

Drawing on all the results presented in this paper, for future policy analysis purposes we would suggest the following elasticity values as most appropriate for NZ:

- *VKT elasticities:*
  Overall: short-run (<1 year) 0.15, long-run (5+ years) 0.30
  Urban: short-run 0.10, long-run 0.20.
- *Fuel consumption elasticities:*
  Overall: short-run 0.20, long-run 0.50.

These estimates are based particularly on our study results plus previous NZ (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 will be evident from Table 9, these recommended values are not very different from the prevailing estimates found internationally.

4.3 Further research directions

The data sets assembled for our study potentially offer the opportunity for further statistical analysis beyond that reported in this paper. We have already undertaken analyses to estimate public transport patronage cross-elasticities with respect to fuel prices, but these are not reported here (but are available in the study report).

Further analyses in the following areas would appear worthwhile:

- Analyses of diesel consumption elasticity with respect to diesel prices, similar to those already undertaken for petrol.
- The study has proven the feasibility of deriving VKT/traffic volume elasticities from traffic count data available in NZ. The traffic volume data set assembled is a rich source, which could now be used to estimate VKT elasticities by region, weekday v weekends etc.
- An unresolved issue is the apparent inconsistency between the study VKT elasticities and consumption elasticities. Further work could be undertaken with the present data set to estimate consumption elasticities for the same period as the VKT elasticities.
- The traffic volume data set collected divides vehicles into four length classes, but to date we have used only the shortest length class (largely cars and light vans) in estimating VKT elasticities with respect to petrol price. Diesel price elasticities could be derived for larger length classes (this is another aspect for which there are very few elasticity estimates internationally).

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Appendix A - Notes on econometric modelling methods

The table following summarises:

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

Further details on the modelling methods used in this study are provided in the study report.

Table 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 estimates	‣ 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 estimates and potential for biased estimates ‣ The 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	$C_t = f(P_t, P_{t-1}, P_{t-2}, \ldots, O_t)$	‣ There is a risk of spurious estimates ‣ The impact of prices on consumption is assumed to follow certain structures (eg 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	$\Delta C_t = f(\Delta P_t,, \Delta O_t)$	‣ There is a high likelihood of over-differencing. ‣ Autocorrelation generally has to be modeled. ‣ Unable to detect long-run effects of prices.	‣ Less risk of spurious estimates	Occasionally used for price elasticities in transport literature
MODELS INTRODUCED OR DEVELOPED FOR THIS TASK				
Differences Models with Lags	$\Delta C_t = f(\Delta P_t, \Delta P_{t-1}, \Delta P_{t-2}, \ldots, \Delta O_t)$	‣ There is a high likelihood of over-differencing. ‣ Autocorrelation generally has to be modeled.	‣ Less risk of spurious estimates ‣ Calculates impact elasticities over time	Occasionally used to calculate price elasticities in other disciplines, but none observed in transport literature See Selvanathan & Selvanathan (1998) for an example.
Season-to-season Differences Models	$\Delta C_t = f(\Delta P_{t-s}, \Delta P_{t-2s}, \Delta P_{t-3s}, \ldots, \Delta O_t)$	‣ There is a high likelihood of over-differencing. ‣ Autocorrelation generally has to be modeled.	‣ Less risk of spurious estimates ‣ 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

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