Motu Working Paper 23-10

Domestic transport charges: Estimation of transport-related elasticities

Motu economic & public policy research

Dean Hyslop, Trinh Le, David Maré, Lynn Riggs and Nic Watson

October 2023

Document information

Author contact details
dean.hyslop@motu.org.nz

trinh.le@motu.org.nz

dave.mare@motu.org.nz

Acknowledgements
This study was supported by the Ministry of Transport. We thank Arthur Grimes, Richard Meade, Euan Richardson, and the project steering group from the Ministry of Transport and Waka Kotahi NZ Transport Agency for helpful comments and suggestions.

Disclaimer
Access to the data used in this study was provided by Stats NZ under conditions designed to give effect to the security and confidentiality provisions of the Data and Statistics Act 2022. The results presented in this study are the work of the author, not Stats NZ or individual data suppliers.

These results are not official statistics. They have been created for research purposes from the Integrated Data Infrastructure which is carefully managed by Stats NZ. For more information about the IDI please visit https://www.stats.govt.nz/integrated-data/.

The results are based in part on tax data supplied by Inland Revenue to Stats NZ under the Tax Administration Act 1994 for statistical purposes. Any discussion of data limitations or weaknesses is in the context of using the IDI for statistical purposes, and is not related to the data's ability to support Inland Revenue's core operational requirements.

The opinions, findings, recommendations, and conclusions expressed in this study are those of the authors, not Statistics NZ, the Ministry of Transport or Motu Economic & Public Policy Research. All opinions and errors should be attributed only to the authors.

Motu Economic and Public Policy Research
PO Box 24390 info@motu.org.nz +64 4 9394250

Wellington www.motu.org.nz

New Zealand

Abstract

In order to better understand the potential effects of transport policies, it is important to understand household spending patterns across different transport-related categories as well as across different households. This study uses three distinct approaches to estimating transport elasticities for New Zealand: cross section, time series, and event studies. The estimated own-price elasticity of fuel demand ranges from –0.1 (very inelastic) based on time-series data to around –2 (very elastic) based on the event-study approach. Using cross-sectional household-level data and regional price variation, we estimate that price elasticity of petrol demand is –0.66 over all households, and ranges from –0.78 for the lowest household expenditure quintile to –0.43 for the highest expenditure quintile, indicating that petrol demand is price-inelastic, and more so for richer households. The different fuel price elasticities estimated by this study represent a range of possible consumer responses when modelling the impact of price changes.

JEL codes

D12 Consumer Economics: Empirical Analysis

R220 Urban, Rural, Regional, Real Estate, and Transportation Economics: Other Demand

Keywords

Price elasticities, transport demand, vehicle kilometres travelled, fuel usage.

DOI: doi.org/10.29310/WP.2023.10

Glossary of terms and abbreviations

2SLS	Two-stage least squares
ABS	Australian Bureau of Statistics
AIDS	Almost ideal demand system
ANZSIC	Australian and New Zealand Standard Industrial Classification
ARFT	Auckland regional fuel tax
CPI	Consumer price index
DiD	Difference in differences
GDP	Gross domestic product
GST	Goods and services tax
HES	Household Economic Survey
IDI	Integrated Data Structure
IV	Instrumental variables approach
LBD	Longitudinal Business Database
MBIE	Ministry of Business, Innovation, and Employment
NZHEC	New Zealand Household Expenditure Classification
NZTA	New Zealand Transport Agency
OECD	Organisation for Economic Co-operation and Development
PBN	Permanent Business Number
QUAIDS	Quadratic almost ideal demand system
RR3	Randomly rounded to base 3
SNZ	Statistics New Zealand
SUR	Seemingly unrelated regression
UK	United Kingdom
VEC	Vector Error Correction estimation model
VKT	Vehicle kilometres travelled
VMT	Vehicle miles travelled
WOF	Warrant of fitness

Contents

Tables

Figures

1 Introduction

This study estimates income and price elasticities of the demand for transport in New Zealand. Income elasticity measures the extent to which the demand for transport changes in response to a change in consumer income, while price elasticity measures how sensitive the quantity demanded of transport is to transport prices or the prices of other goods. Understanding transport demand responsiveness is important for formulating policies that target the externalities from transport use such as emissions.

Transport is one of New Zealand’s largest sources of emissions, accounting for approximately 17 per cent of gross domestic emissions and 39 per cent of total domestic CO2 emissions (Ministry for the Environment, 2022a). In order to reach net-zero long-lived emissions by 2050, the government has set a goal to reduce transport emissions by 41 per cent by 2035 from 2019 levels (Ministry for the Environment, 2022b).

To reduce transport emissions, policies will need to influence transport demand – the type and quantity of travel that people would choose. Impacts of transport policies are often measured using elasticities, defined as the percentage change in demand for a transport mode in response to a one-percent change in one of its determinants, such as its price, travel speed, income, or the availability of other transit services. New Zealand households allocate approximately 16% of their total expenditure to transport, which is on the high end relative to other OECD countries (Ministry of Transport, 2022). Thus, transport policies are likely to exert considerable impacts on households.

In order to better understand the potential effects of transport policies, it is important to understand household spending patterns across different transport-related categories as well as across different households. Fuel prices may be only one aspect that households consider when deciding between driving a private vehicle or taking public transport. Commuters to congested downtown areas, for example, may also consider parking fees as well as their ability to easily find convenient parking. Moreover, different households will face different constraints in their ability to counter changing prices. In rural areas, for example, households may have fewer public transportation options than households in denser urban areas. Lower-income households may also have fewer options for purchasing more fuel-efficient vehicles or moving closer to their jobs than higher-income households as lower-income households tend to be more capital constrained.

There is a long-established and rich literature on transport elasticities (for example, Wardman’s (2022) meta-analysis covers 2,131 price elasticities from 204 UK studies). Given the central role that carbon pricing policies have played in mitigation strategies, much of the recent literature has focused on the impact of fuel prices on outcomes directly related to emissions, such as petrol usage and distance travelled. Most New Zealand studies in this area have analysed the former, as data on the latter are limited. Three main types of data are used in studies on transport elasticities: aggregate data, household- or individual-level survey data, and high-frequency, transaction-level data. Different data types can result in markedly different elasticities estimates, which might reflect different types of response, or simply be due to different estimation methods.

In view of the pros and cons of the different types of data available, this study uses three distinct approaches to estimating transport elasticities for New Zealand. First, we use household-level expenditure data to estimate income, own-price and cross-price elasticities of demand for fuel. Second, we estimate short-run and long-run elasticities of aggregate fuel consumption with respect to fuel price, using national time-series analysis. Third, we estimate local fuel demand elasticities based on fuel sales responses to the Auckland regional fuel tax (ARFT), introduced in 2018. The study thus combines three of the revealed preference approaches identified by Wallis (2004) – cross section, time series, and event studies, and considers a range of consumer responses to price changes: household, aggregate economy, short-run, long-run, and local market.

Even though fuel in general is the main transport good of interest in this study, due to data constraints it is defined rather differently across our three analyses. In the household-level analysis fuel is defined as petrol, as regional price data are available for petrol specifically but not for fuel in general. Aggregate fuel consumption data do not distinguish between consumption by households versus consumption by non-households. Thus, the time-series analysis is restricted to petrol consumption to keep the focus on the household sector. In the ARFT analysis, data on total sales of fuel outlets, which do not distinguish between different types of fuels or between fuels and non-fuels, are used as a proxy for total sales of all types of fuels.

Although the approaches have conceptually similar objectives with regards to the own-price elasticity of fuel, they differ in several important respects. First, the household-level expenditure data necessarily focuses only on private household responses, while the time-series and regional fuel tax analyses focus on aggregate expenditure, including commercial users. Second, different time periods are covered by the household-level (2006/7–2018/19) and time-series (1978–2019) analyses, while the ARFT analysis presents an event study over the recent past (2018–2022). Third, the time-series analysis focuses on controlling for secular trends at the aggregate (national) level, whereas the household-level analysis exploits regional variation in fuel prices and controls for prices of other goods and broad household characteristics. Finally, the analysis of responses to the ARFT includes (and is perhaps dominated by) spatial responses of *where* to purchase fuel as well as fuel consumption per se.

Given the limitations of the different data sets, these different approaches allow us to examine the issue more robustly. For example, the household-level data approach provides detailed information about household spending patterns and behaviour; however, small sample sizes may limit the analysis in other ways (e.g., generalisability). The time-series approach provides a broader perspective with much larger sample sizes, but with much less detailed information about individuals and households in the analysis.

The rest of the report proceeds as follows. Section 2 reviews the literature on modelling and estimating demand elasticities for transport goods. In sections 3-5 we describe the methods and data before presenting estimation results for each analysis. Section 3 estimates own-price, cross-price and income elasticities of demand for fuel and other transport using household-level expenditure data. Section 4 uses national time-series analysis to estimate fuel demand elasticities with respect to fuel price. Section 5 estimates fuel demand elasticities based on fuel sales responses to the ARFT. Section 6 summarises and concludes.

2 Literature review

Numerous studies have examined the effects of rising fuel prices on transport demand. Given the central role that carbon pricing policies have played in mitigation strategies, the recent literature has focused on fuel usage and distance travelled. This section summarises studies on elasticities of fuel usage (section 2.1), distance travelled (section 2.2) as well as the relationship between transport prices and other modes of travel such as public transport and cycling (section 2.3). New Zealand studies are highlighted in section 2.4.

2.1 Elasticity of fuel demand

A common proxy for private vehicle utilisation is the consumption of petrol. This measure is often preferred due to its more direct relation to emissions, a common policy outcome of interest. Papers investigating the price sensitivity of petrol consumption take on various data-driven approaches which can affect their measure of elasticity. For example, Levin et al. (2017) demonstrate that higher levels of temporal and spatial aggregation introduce biases that result in more inelastic demand estimates.

To illustrate this purported effect of spatial aggregation, we consider a handful of international studies (predominantly from the US). Those that employ aggregate administrative data (Hughes et al., 2008; Park and Zhao, 2010; Small and Van Dender, 2007) generally estimate price elasticities to be around –0.03 to –0.3. By contrast, studies that use household- or individual-level survey data (Nicol, 2003; Schmalensee and Stoker, 1999; Puller and Greening, 1999; Kayser, 2000; Kim, 2007) find higher price elasticities, generally around –0.2 to –1.1. A small number of studies use high-frequency, transaction-level data to model individuals' responses to shifts in price over a shorter time horizon (Knittel & Tanaka, 2021; Levin et al., 2017). These few studies have resulted in middling price elasticity estimates of –0.27 to –0.37.

A more comprehensive review of the methodological drivers of differences in price elasticity estimates is provided by meta-analyses of UK studies by Wardman (2014; 2022) for different modes of travel (car, bus, rail). Key insights from these meta-analyses include the following:

- Static elasticities (i.e. those estimated from models that do not incorporate time lags) tend to be slightly larger than short-run elasticities, but long-run elasticities[1] tend to be the largest, and static elasticities can be used to estimate long-run elasticities.
- The ratio of long-run to short-run elasticities from the same model for all travel modes seems to be fairly consistent, at around 2 (the mean estimated in Wardman (2022) is 1.86). For cars the mean ratio estimated in Wardman (2022) is 2.54. Furthermore, the long run (indicated by 95% of the effect working through) tends to be around three years.
- Cross-sectional data can be problematic for estimating some elasticities. One concern with elasticities derived from cross-sectional demand data for public transport modes is that increased demand can induce operators to increase prices especially in less regulated markets. This is known as simultaneity bias.
- Elasticities for car travel based on total cost data are (approximately three times) larger than those based on partial cost (i.e., fuel alone).

[1] Short- and long-run elasticities were distinguished by the lagged values used in the estimation.

- There does not seem to be any evidence of systematic changes in elasticities over time in the UK. Implied long-run elasticities range from –0.08 to –0.63 for car, –0.59 to –1.35 for rail and –0.28 to –0.91 for bus.

It is important to distinguish between short-run and long-run elasticities. In the short-run, extensive-margin choices such as housing location, work location, vehicles, and commuting modes and supply (e.g. availability of public transport) tend to be fixed, household choices are confined to intensive margins, thus transport demand tends to be inelastic. In the long run, supply constraints are lessened and households have greater flexibility to adjust their extensive-margin choices, hence long-run elasticities tend to be higher.

2.2 Elasticity of distance travelled

Studies analysing the response of distance travelled, often termed vehicle kilometres travelled (VKT) or vehicle miles travelled (VMT, in the US literature), have examined issues such as the offsetting effects of increased fuel efficiency, where the cost of driving per kilometre is reduced due to the improved efficiency, thereby increasing VKT, all else equal.

A variety of different data types have been used to examine this:

- aggregate time-series administrative data (Greene, 1992; Small & Van Dender, 2007),
- micro-level survey data (Pickrell & Schimek, 1999; West, 2004),
- odometer readings during vehicle checks (Knittel & Sandler, 2011).

The same data-driven methodological differences that apply to petrol elasticities also apply to VKT studies. For instance, larger disparities exist in studies that use micro-level survey data than those that use aggregate data.

Studies of VKT have revealed valuable insights into behavioural responses to fuel price changes. Small and Van Dender (2007) find that responses in the short-run (1 month, in their case) are generally limited, resulting in smaller elasticities. By comparison, long-run VKT elasticity estimates are 4-5 times the size of their short-run counterparts. Knittel (2012) concurs that short-run responses are generally limited, but states that long-run elasticity is more difficult to estimate, due to a lack of sustained (exogenous) price increases over long time periods. Knittel and Sandler (2011) find that heavily polluting vehicles are more responsive to fuel price changes than cleaner vehicles.

One of the main challenges of measuring transport utilisation is the endogenous nature of vehicle ownership and vehicle utilisation (e.g., buying a more fuel-efficient car compared to using it more regularly or for longer trips). To account for this endogeneity, many papers consider both aspects. Early papers such as Goldberg (1998) tended to do this sequentially, with models that estimate vehicle choice and VKT separately. More recently, papers have tended to model these simultaneously (Feng et al., 2013; West, 2004).

2.3 Modal alternatives to private vehicle transport

In addition to papers that investigate private use of internal combustion engine vehicles, many studies of transport demand extend their analysis to other modes of transport, predominantly public transport, but occasionally to other modes as well (e.g. taxi services (Bergantino et al., 2018), and electric cars (Bushnell et al., 2022)).

Papers investigating alternative transport modes are often concerned with the effects of income on consumption patterns, i.e. income elasticities. Bergantino et al. (2018) find rail and bus services are a strong luxury in most income groups, except blue-collar communities, for which rail is a necessity. Bergantino (1997) suggests that, in general, transport products and services are necessities at higher levels of income and luxuries at lower ones. Berri et al. (1998) investigate public and private transport demand across Poland, France, Canada, and the US. They find that public transport is a luxury good in France, but a normal good in Canada. Also, consistent across all countries, they find that income elasticities for transport are larger for lower-income households.

A handful of studies examine the change in demand of different modes of transport with respect to a change in petrol prices including several studies in a New Zealand context (Wallis, 2004; Kennedy & Wallis, 2007; Sheng & Sharp, 2019; Torshizian & Isack, 2020). These are generally modelled as cross-price elasticities. However, Wallis (2004) highlights that cross-price elasticity methods are sensitive to base mode shares and, as an alternative, suggests a 'diversion rate' approach, which involves multiplying the direct price elasticity of private transport by the proportion of change in private transport demand that switches to or from the mode of interest.

2.4 New Zealand studies

Studies of transport demand in New Zealand generally have a broad focus, considering not only private transport, but public transport demand and the interaction between the two.

Wallis (2004) investigates the transport elasticity literature, with a particular focus on New Zealand and Australian evidence, to propose a range of elasticities that may be appropriate for transport demand forecasting in New Zealand. These include elasticities relating to public transport, private (vehicle) transport, cross-elasticities, and diversion rates of private transport costs on public transport. He suggests an appropriate range for direct price elasticities of public transport is –0.2 to –0.6 for bus and –0.2 to –0.5 for rail. Elasticities of private transport with respect to petrol cost tend to lie between –0.1 to –0.2 in the short-run and –0.2 to –0.3 in the long-run.[2]

Kennedy and Wallis's (2007) results generally conform to these ranges. They also extend their consideration to road traffic levels (VKT) and find that VKT elasticities differ between urban peak, urban off-peak, and rural travel. They suggest short-run (1-year) VKT elasticities of–0.09, –0.27, and –0.12 for urban peak, urban off-peak, and rural travel respectively. The corresponding medium-run (2-year) elasticities are –0.24, –0.36, and –0.19.

Endogeneity is a key challenge of these studies. For example, increasing petrol prices may also affect the cost of public transport, especially those dependent on petrol (e.g., buses). Simic and Bartels (2013) suggest combining Two-Stage Least Squares (2SLS) models with Seemingly Unrelated Regression (SUR) models to account for this endogeneity and that of various explanatory variables used in the analysis.

Sheng and Sharp (2019) simultaneously estimate a system of VKT equations using a SUR model for four different transport modes (petrol cars, diesel cars, buses, and petrol motorcycles) using quarterly time-series data (2001–2015) to analyse aggregate road transport demand in terms of contemporaneous fuel prices, bus fares, fleet age, and other population characteristics. Their results indicate that petrol vehicle VKT and diesel vehicle VKT demand are inelastic with respect to their

[2] This range is similar to US studies that use highly aggregated data, but smaller (less elastic) than those that use more disaggregated, household- or individual-level data.

own fuel prices (–0.08 and –0.10 respectively) but no other significant relationships between other price and VKT measures. They also find that bus VKT and motorcycle VKT are inferior goods (income elasticities are –2.7 and –4.6 respectively) and that increasing unemployment also significantly reduces both. Diesel VKT is negatively affected by unemployment and by the average age of the fleet of diesel vehicles. Finally, their results also indicate that petrol cars, diesel cars, and motorcycles are substitutes but that these are all complementary to buses.

More recently, Torshizian and Isack (2020) apply a demand-system model to estimate own- and cross-price elasticities of demand for public transport, with respect to private transport, housing and food. While the scope of this study is restricted to the Auckland region, their use of administrative datasets should allow this procedure to be applied more widely.

Torshizian and Meade (2020) examine the use of demand estimation for competition analysis, but in so doing, they estimate own- and cross-price elasticities for accommodation, electricity, food, and petrol. They do so for different markets in New Zealand (all of New Zealand, large urban areas, medium urban areas, and small urban areas)[3] and for households in these different markets. At the market level, they find that petrol price increases are associated with significant reductions in demand for petrol except in medium urban areas,[4] and that petrol and accommodation are complements in all markets except small urban markets where petrol and accommodation are substitutes. At the household level, their findings indicate that a change in the price of petrol does not significantly change households' expenditure on petrol. While Torshizian and Meade (2020) control for different household characteristics (region, composition, and size), they do not estimate elasticities for different household types.

Our study extends the New Zealand literature in two ways. First, it takes advantage of a natural experiment (the ARFT) to examine how fuel consumption responds to changes in prices. Second, it estimates own- and cross-price elasticities of demand for different population groups (e.g., lower vs. higher income levels, rural vs. urban). According to Wardman (2022), very little work has been done on estimating price elasticities for different income and demographic groups. This study will shed light on the extent to which transport demand varies across population groups.

[3] Large urban areas include Auckland and Wellington, medium urban areas include Christchurch, Dunedin, and Hamilton, and small urban areas include the rest of New Zealand. The market-level own-price elasticities were –1.83 for all of New Zealand, –2.69 for large urban areas, and –2.20 for small urban areas.

[4] Their estimate of elasticity for this market was insignificant.

3 Household expenditure analysis – Elasticities of fuel demand

3.1 Analytical approach

Most contemporary papers that model demand use the Deaton and Muellbauer (1980) Almost Ideal Demand System (AIDS), or some variation of it. One of the earlier studies to use AIDS to model demand in New Zealand was by Mhurchu et al. (2013),[5] who apply household-level expenditure data from the Household Economic Survey (HES) and the Consumer Price Index (CPI) data to a linearised version of AIDS to estimate elasticities for different food categories. They extend the standard model by adding demographic covariates such as income and ethnicity. Thomas (2019), Torshizian and Meade (2020) and Stephenson (2021) use essentially the same data, but estimate a Quadratic AIDS (QUAIDS) model. Developed by Banks et al. (1997), QUAIDS is an extension to the AIDS; it is more flexible than the AIDS in that it allows elasticities to vary across the income distribution.[6]

We use a QUAIDS model to estimate own-price, cross-price, and income elasticities of different types of transport expenditures. Following Poi (2012), the primary estimation equation for this analysis will be as follows:

$$w_i = \alpha_i + \sum_{j=1}^{k} \gamma_{ij} \ln p_j + (\beta_i + \boldsymbol{\eta}_i' \boldsymbol{z}) \ln\left\{\frac{m}{\bar{m}_0(\boldsymbol{z}) a(\boldsymbol{p})}\right\} + \frac{\lambda_i}{b(\boldsymbol{p}) c(\boldsymbol{p}, \boldsymbol{z})} \left[\ln\left\{\frac{m}{\bar{m}_0(\boldsymbol{z}) a(\boldsymbol{p})}\right\}\right]^2 \quad (1)$$

where w_i is the share of a household's total expenditure m spent on good i at price p_i in quantity q_i. Hence, $w_i = \frac{p_i q_i}{m}$ for $i = 1, 2, \cdots, k$. $\boldsymbol{z}$ is a vector of household characteristics, $\bar{m}_0(\boldsymbol{z})$ measures the change in household expenditures given different household characteristics not controlling for changes in consumption patterns, and $c(\boldsymbol{p}, \boldsymbol{z})$ controls for changes in relative prices and different consumption patterns for different household types.

That is, how much a household spends on good i depends on the relative prices of other goods (to good i), the household's income level (represented by expenditure) and its tastes (represented by household demographic characteristics).

The uncompensated price elasticity of good i with respect to changes in the price of good j is

$$\begin{aligned}\epsilon_{ij} = -\delta_{ij} + \frac{1}{w_i}\Bigg(\gamma_{ij} - \left[\beta_i + \boldsymbol{\eta}_i' \boldsymbol{z} + \frac{2\lambda_i}{b(\boldsymbol{p}) c(\boldsymbol{p}, \boldsymbol{z})} \ln\left\{\frac{m}{\bar{m}_0(\boldsymbol{z}) a(\boldsymbol{p})}\right\}\right] \times \left(\alpha_i + \sum_l \gamma_{il} \ln p_l\right) \\ - \frac{(\beta_j + \boldsymbol{\eta}_j' \boldsymbol{z})\lambda_i}{b(\boldsymbol{p}) c(\boldsymbol{p}, \boldsymbol{z})} \left[\ln\left\{\frac{m}{\bar{m}_0(\boldsymbol{z}) a(\boldsymbol{p})}\right\}\right]^2\Bigg) \quad (2)\end{aligned}$$

The expenditure (income) elasticity for good i is given by:

---

[5] Michelini (1999) estimated an AIDS model using semi-aggregated annual household expenditure data, whereas Khaled and Lattimore (2006, 2008) used household-level data but estimated a Rotterdam demand model.

[6] Alternatively, Marilena and Francesco (2017) alter the AIDS to model demand at different tails of the income distribution. Another useful extension is offered by Holt and Goodwin (2009), who incorporate demographic effects into the AIDS model.

$$\mu_i = 1 + \frac{1}{w_i}\left[\beta_i + \boldsymbol{\eta}_i'\boldsymbol{z} + \frac{2\lambda_i}{b(\boldsymbol{p})c(\boldsymbol{p},\boldsymbol{z})}\ln\left\{\frac{m}{\overline{m}_0(\boldsymbol{z})a(\boldsymbol{p})}\right\}\right] \qquad (3)$$

Compensated price elasticities can be derived from the Slutsky equation:

$$\epsilon_{ij}^{C} = \epsilon_{ij} + \mu_i w_j \qquad (4)$$

Since m could be total household expenditure for all goods purchased by the household or the total expenditure for a subset of goods, we examine the effects of analysing these shares in terms of total expenditure and in terms of total transport expenditure.

3.2 Data sources

This analysis uses household-level expenditure data from the HES and price data from the CPI.

Household expenditure data

The HES is a major survey conducted by Statistics New Zealand to collect information on household income, savings, and expenditure, as well as demographic information on individuals and households. Since its inception in 1973, the HES has undergone several redevelopments, most importantly in 2006/07 and 2018/19. Currently the HES has three components: HES Income, HES Expenditure, and HES Net worth. Each survey is usually run from July to June. The HES Expenditure collects itemised household expenditure for calculating the expenditure weights of items in the CPI. There have been six HES Expenditure surveys since the 2006/07 redevelopment: 2006/07, 2009/10, 2012/13, 2015/16, 2018/19 and 2021/22. We use all but the last HES Expenditure survey in our analysis.[7]

The expenditure component of HES asks respondents about their household expenditures using both recall and diary methods. When the household is interviewed, they are asked about expenditures using a 3-month recall for large or irregular expenditure types (e.g., health, travel); using 12-month recall for housing-related expenditures; and using the latest payment for regular expenditures (e.g., utilities, rates, rent, insurance). All household members aged 15 years and older are also asked to keep a diary record of all their expenditures for a specified period.[8]

Transport expenditures are primarily asked via a questionnaire with a 12-month recall (e.g., vehicle purchases, vehicle sales, vehicle repairs, parts, and accessories). However, licensing, registration, and insurance expenditures are asked in terms of the most recent payment and the period covered by that most recent payment. Travel expenditures are separated into those which have a transport component (e.g., air fares, public transport, taxis) and those which do not (e.g., accommodation).

In HES, each expenditure item is denoted by the survey module from which it was collected (e.g., transport, travel, housing, diary) as well as a detailed expenditure code from the New Zealand Household Expenditure Classification (NZHEC) which denotes the product or service purchased. Some products or services with the same NZHEC code can fall under different expenditure modules. For example, some vehicle purchases are classified under the recreation module, though the vast majority are classified under the transport module.

[7] Data on HES 2021/22 are expected to be available from March 2024. There was a continuity break in the survey design that reduces the comparability of data in the years prior to 2006/07. Moreover, earlier years are not currently available in this project. Nevertheless, the available years provide a sufficient sample for us to analyse.

[8] Respondents kept a 14-day diary of expenditures until the 2018/19 survey when the diary duration was changed to 7 days to reduce respondent burden. More information can be found on the Statistics New Zealand website: https://www.stats.govt.nz/methods/changes-to-the-household-economic-survey-201819.

There does not seem to be a standard methodology for classifying transport-related expenditures, with most papers focusing on fuel expenditures. Most of the classifications we find, however, classify expenditures separately for private vehicles and public transport. For private vehicles, expenditures are often categorised into vehicle ownership costs (purchase or lease, insurance, licensing, registration, financing) and vehicle operating costs (fuel and oil, maintenance, tyres). We follow a categorisation developed by Statistics New Zealand (2018) for a transportation cost index which also allows us to follow the general classifications seen in the literature. The full classification is provided in Appendix A1. These expenditure classifications are also similar to the CPI classes for transport prices discussed below.

Price data

New Zealand CPI data can be disaggregated into 11 (level 1) groups,[9] which can then be further disaggregated into 44 sub-groups (level 2) and 109 classes (level 3). The 'transport' group in particular consists of 14 classes (see Appendix A2). Complete national price indices at each of the three levels have been available quarterly since April 1999. Food, one of the 11 groups, has quarterly price indices going back to July 1925 (monthly since January 1960).

There are also regional price indices for certain groups and classes. These indices are disaggregated by five broad regions: Auckland, Wellington, Rest of North Island, Canterbury, and Rest of South Island. Since April 2006, quarterly regional price indices have been available for nine (except for Communication and Education) of the 11 groups (see list in footnote 9), and also for three (Actual rentals for housing; Purchase of housing; Petrol) of the 109 classes. Monthly food price indices are available for 15 main centres[10] since December 1993 and for the five broad regions since June 1999.

Existing New Zealand studies that estimate elasticities based on household-level expenditure data and an AIDS model also use CPI data. In particular, Mhurchu et al. (2013) use the monthly food price index for the 15 main centres, whereas Thomas (2019) and Stephenson (2021) mainly draw on regional CPI for five broad regions. While those three studies use price indices, Torshizian and Isack (2020) and Torshizian and Meade (2020) use the price data that Statistics New Zealand uses as an input in compiling the indices, available for 501 product categories at the regional level. However, these data are not available to us. Hence, we use regional CPI data, similar to Thomas (2019) and Stephenson (2021).

Household expenditures categories

In order to disaggregate expenditure data a few competing requirements are considered. On the one hand, disaggregation should be detailed enough to provide meaningful differentiation between one type of expenditure to another and to allow for disaggregation within the transport group. On the other hand, disaggregation should be high level enough so as not to distract the focus from transport and take unnecessarily long time to process.[11] Furthermore, expenditure categories need to align with regional CPI categories. Given that, we start with 18 categories of household expenditures. Appendix Table 1 shows how each expenditure category corresponds to NZHEC codes in the HES

[9] The 11 groups are: Food; Alcoholic beverages and tobacco; Clothing and footwear; Housing and household utilities; Household contents and services; Health; Transport; Communication; Recreation and culture; Education; Miscellaneous goods and services.

[10] The 15 main centres are: Whangarei, Auckland, Hamilton, Tauranga, Rotorua, Napier-Hastings, New Plymouth, Wanganui, Palmerston North, Wellington, Nelson, Christchurch, Timaru, Dunedin, and Invercargill. The indices for Rotorua and Timaru were discontinued from July 2014.

[11] For example, 20 expenditure groups result in 400 own- and cross-price elasticities.

and the CPI data disaggregation.[12] We exclude three expenditure categories (Interest payments, Miscellaneous cash expenses, Sales, trade-ins and refunds) because they are not included in the calculation of CPI (and hence no price data for them). We further exclude 'Credit services' because it is a small category on its own, and it is not straightforward which other category to aggregate this category with. Together these four categories make up 7.07% of total household expenditure in 2018/19 (Statistics New Zealand, 2020).

Total expenditures across the 18 categories included in Appendix Table 1 averages $58,500 (June 2019 prices) per household in the estimation sample. As shown in Appendix Table 2 (column 1), categories with the largest budget shares include Housing (22.6%), Groceries (13.6%) and Recreation & culture (10.7%), while the smallest budget shares are under 3% (Alcohol & tobacco, Air transport, Other private transport, and Education). Demand system analysis based on this breakdown either did not converge, or yielded highly implausible estimates (e.g. price elasticities for 'Public transport' and 'Air transport' of around 100). This could be because there is insufficient variation in the price data for identification.[13] The issue is exacerbated by the fact that due to the lumpiness of expenditures of certain types (e.g. durables) as well as the relatively short diary-keeping period (7 days in HES 2018/19 and 14 days previously), only small proportions of households report expenditures for those in each period. For example, around three quarters of the sample did not report any expenditures on Vehicle purchase and Education (column 2). Since we equate expenditure to consumption, this data issue treats households with positive expenditures as having high consumption, and households with zero expenditures as having no consumption, resulting in implausible estimates.

Following the literature, we address this issue by excluding durable expenditures and aggregating smaller categories, especially those that already share the same price data (see Appendix Table 1, column 3). In particular, we drop Housing, Household contents and Vehicle purchase because they are primarily durables, and exclude durables items (audio-visual equipment, computing equipment, and major recreational and cultural equipment) from Recreation & culture. As a result, total expenditure now averages $38,100 per household, (i.e. the excluded durables account for about 35% of the old total average). Furthermore, we combine Groceries and Eating out into 'Food', Other private transport, Public transport and Air transport into 'Other transport', and Communication, Education, Personal miscellaneous and Insurance into 'Miscellaneous'. This results in nine expenditure categories, as shown in Appendix Table 2 (column 3).

3.3 Household-analysis results

This section presents estimates of expenditure elasticities and price elasticities. We start with results from our baseline specification. Section 3.3.2 checks the robustness of the baseline results by showing how sensitive the results are when some of the underlying modelling assumptions are changed. Section 3.3.3 then presents estimates of elasticities for different income and demographic groups.

[12] This classification is similar to that used in Stephenson (2021); the major difference is that Stephenson further disaggregates 'household energy' while we have a finer breakdown of 'transport'.

[13] Thomas (2019) also reports this issue (ibid., page 10).

3.3.1 Baseline results

Around 2,900-3,900 households responded in each of the five HES Expenditure surveys (2006/07, 2009/10, 2012/13, 2015/16 and 2018/19). Our estimation sample includes 16,221[14] households, which represent almost 99%[15] of the total responding sample. The 2018/19 survey accounts for 24% of the total estimation sample, while each of the first three surveys accounts for 17-19% of the sample (see Appendix Table 3). Pooling the sample across surveys is necessary not just to improve the sample size for disaggregated demographic analysis, but also to add variation in the price data. (As discussed in section 3.2, the price data contain little geographic variation.) Since CPI data are quarterly, we match with the quarter of interview date in the HES data to provide intra-year variation in prices.

Elasticities are obtained by estimating equation (1) using command *quaids* developed by Poi (2012) in Stata.[16] Our baseline model controls for seven household characteristics ($\boldsymbol{z}$): household size, number of children, dummies for whether household has people aged 65 or over, Māori, migrant, whether the highest education level achieved by any household member is a university degree or above, and whether the dwelling is rurally located. These characteristics are designed to capture differences in tastes across different types of households.[17] Table 1 reports mean budget shares, estimated expenditure elasticities and price elasticities from the baseline model, evaluated at the means of all variables.

Expenditure elasticity

In this study expenditure elasticity is used as a proxy for income elasticity, which measures the extent to which the demand for a good changes in response to a change in consumer income. Expenditure elasticities, estimated based on equation (3), vary across the expenditure distribution. Median expenditure elasticities, presented in Table 1 (column 2), indicate that all expenditure categories are normal goods.[18] Four categories can be classified as necessities as they have expenditure elasticities lower than one (Food, Household energy, Petrol, and the Miscellaneous category which includes Education, Communication, Insurance, and Personal miscellaneous). Five categories are found to be luxuries due to having expenditure elasticities well in excess of one (Alcohol & tobacco, Clothing & footwear, Health, Other transport, Recreation & culture). These findings are largely in line with expectations of what constitute necessity goods and luxury goods.

---

[14] All counts of people and businesses reported in section 3.3 and 5.4 have been randomly rounded to base 3 (RR3) to protect confidentiality. All proportions have been calculated based on RR3 counts.

[15] The remaining 1% are excluded because they have missing data on expenditures or key demographic variables.

[16] A major drawback of *quaids* is that it does not calculate standard errors for elasticity estimates. Standard errors are calculated by its successor *demandsys*, only available in Stata 18 but as of August 2023 Statistics New Zealand data lab is using Stata 16. Alternative commands in Stata 16 only estimate the linear approximation of QUAIDS.

[17] We experimented with more demographic controls, however, this tends to increase processing time or result in non-convergence. A robustness check in section 3.3.2 shows that the number of controls does not have a material effect on elasticity estimates at the means.

[18] Normal goods are goods for which demand increases when income increases, i.e. normal goods have positive income elasticities. Both 'necessity' goods and 'luxury' goods are normal goods. Inferior goods have negative income elasticities.

Table 1: Baseline expenditure elasticities and own-price elasticities

	Mean budget share	Median expenditure elasticity	Uncompensated price elasticity	Compensated price elasticity
	(1)	(2)	(3)	(4)
Food	0.283	0.834	-0.911	-0.659
Alcohol & tobacco	0.043	1.009	-1.622	-1.575
Clothing & footwear	0.053	1.484	0.299	0.365
Household energy	0.064	0.228	-0.413	-0.390
Health	0.047	1.500	-1.181	-1.121
Petrol	**0.060**	**0.846**	**-0.660**	**-0.605**
Other transport	**0.096**	**1.446**	**-2.257**	**-2.149**
Recreation & culture	0.131	1.532	-0.617	-0.441
Miscellaneous	0.222	0.962	-0.094	0.120

Source: Estimated from Household Economic Survey 2006/07, 2009/10, 2012/13, 2015/16, 2018/19

Note: Miscellaneous includes Education, Communication, Insurance, and Personal miscellaneous from Appendix Table 1

Expenditure elasticities are estimated in a few recent New Zealand studies, however comparing our estimates with them is not straightforward due to differences in expenditure groupings across studies. As summarised in Table 2, the common findings across these studies are that all of them find food and petrol/fuels to be necessities and Alcohol & tobacco, Clothing & footwear, Health, Non-fuels transport, and Recreation & culture to be luxuries. This study estimates the median expenditure elasticity for Alcohol & tobacco to be 1.01, in line with Thomas (2019), Torshizian and Meade (2020) and Stephenson (2021) who estimate it to be 1.14, 1.14–1.16 and 1.15 respectively. Thus, Alcohol & tobacco are borderline between necessities and luxuries.

The current study estimates the miscellaneous category (education, communication, insurance, and personal miscellaneous) to be necessities. By comparison, Stephenson (2021) estimates education and communication (as separate categories) to be necessities, and insurance and personal miscellaneous (separately) to be luxuries. Thomas (2019) estimates the aggregate category consisting of household utilities, communication and education to be necessities, personal miscellaneous to be luxuries while insurance is not included.

Our finding that household energy is a necessity good is inconsistent with Torshizian and Meade's (2020) finding that electricity is an inferior good. However, this is in line with Thomas's (2019) finding that household utilities (which includes household energy), communication and education as a group are necessities and Stephenson's (2021) finding that Electricity and Other energy are (separately) necessities.

Table 2: Summary of findings on expenditure elasticities and own-price elasticities in recent New Zealand studies

	Current study	Stephenson (2021)	Torshizian and Meade (2020)	Torshizian and Isack (2020)*	Thomas (2019)
Data source	HES 2006/07, 2009/10, 2012/13, 2015/16, 2018/19	HES 2006/07, 2009/10, 2012/13, 2015/16, 2018/19	HES 2006/07, 2009/10, 2012/13, 2015/16	HES 2006/07, 2009/10, 2012/13, 2015/16	HES 2000/01, 2003/04, 2006/07, 2009/10, 2012/13, 2015/16
Method	QUAIDS	QUAIDS	LA-AIDS	LA-AIDS	QUAIDS
Software	*quaids* in Stata	Adapted from *MicEconAids* in R	*nlsur* and *nlsuraids* in Stata	*nlsur* and *nlsuraids* in Stata	*aidsills* in Stata
Number of expenditure categories	9	17	7	4	9
Luxuries	Alcohol & tobacco; Clothing & footwear; Health; Other transport; Recreation & culture	Eating out; Alcohol & tobacco; Clothing & footwear; Household contents; Health; Air transport; Recreation & culture; Mortgage interest; Insurance; Miscellaneous	Accommodation; Alcohol; Cigarettes	Pubic transport; Housing	Alcohol & tobacco; Clothing & footwear; Healthcare; Transport excluding fuels; Recreation & culture; Personal miscellaneous
Necessities	Food; Household energy; Petrol; Miscellaneous	Groceries; Accommodation; Electricity; Other energy; Transport; Communications; Education	Petrol; Food	Food; Private vehicle	Food; Transport fuels; Household utilities, communication and education
Inferior goods		-	Electricity; Chocolate	-	-
Price elastic	Alcohol & tobacco; Health; Other transport	Clothing & footwear; Accommodation; Electricity; Household contents; Health; Communications; Recreation & culture	Electricity; Petrol; Alcohol	Food; Public transport; Housing	Transport excluding fuels; Personal miscellaneous; Household utilities, communication and education
Price inelastic	Food; Household energy; Petrol; Recreation & culture; Miscellaneous	Groceries; Eating out; Other energy; Air transport; Transport; Mortgage interest; Insurance; Miscellaneous	Food; Chocolate; Cigarette	Private vehicle	Food; Alcohol & tobacco; Clothing & footwear; Healthcare; Transport fuels; Recreation & culture
Positive price elasticity	Clothing & footwear	Alcohol & tobacco; Education	Accommodation		-

Notes: Transport goods are highlighted. 'Miscellaneous' is defined differently across studies. *Auckland region only.

Own-price elasticity

Own-price elasticity measures how sensitive the quantity demanded of a good is to its own price. There are two types of price elasticity: one based on the uncompensated (or Marshallian) demand curve and the other based on the compensated (or Hicksian) demand curve. The difference between uncompensated elasticity and compensated elasticity is that the former holds constant consumers' nominal income while the latter holds constant real income. By definition (see equation 4), this difference depends on the relative importance of the good in consumer's budget and the income elasticity. For normal goods compensated elasticities are higher, which means that these goods are less price elastic based on compensated elasticities than uncompensated elasticities. In our demand system of nine expenditure categories, the differences between the two types of price elasticity are not large, hence for conciseness we focus on uncompensated elasticities.

Our estimates reveal that four categories are classified as price elastic, having price elasticities less than –1 (Alcohol & tobacco, Health, and Other transport) while five are considered price inelastic (price elasticity between –1 and 0: Food, Household energy, Petrol, Recreation & culture, and Miscellaneous). Clothing & footwear is estimated to have positive price elasticity, indicating that it has an upward-sloping demand curve. Since the expenditure elasticity of this category is greater than one (column 2), positive price elasticity suggests that Clothing & footwear is a Veblen good, a type of luxury good for which the demand increases as the price increases.

No common patterns can be found in price elasticities across the recent New Zealand studies (bottom panel of Table 2). For example, like Thomas (2019), the current study estimates Petrol to be price inelastic and Other transport (of which air transport and public transport are components) to be price elastic. This is roughly in line with Torshizian and Isack (2020), who find private vehicle transport to be price inelastic and public transport price elastic. However, Stephenson (2021) finds air transport to be price inelastic, while Torshizian and Meade (2020) find petrol to be price elastic. Nevertheless, this is not unexpected. Different studies have different focuses, and thus categorise expenditures differently. As a result, estimated parameters and hence price elasticities vary markedly across definitions of good and associated prices.

Cross-price elasticity

Cross-price elasticity measures the responsiveness of the quantity demanded for a good to the change in the price of another good. Two products are considered complements if their cross-price elasticity is negative and substitutes if their cross-price elasticity is positive. Table 3 presents cross-elasticities (evaluated at the means) between transport goods and other goods.

Petrol is found to be a substitute for Alcohol & tobacco, Clothing & footwear, Household energy, and Other transport, meaning an increase in the price of these categories will increase the demand for Petrol, and vice versa. Petrol is complementary with Health, Recreation & culture, and the Miscellaneous category, meaning an increase in the price of these categories will lower the demand for Petrol, and vice versa. Other transport is complementary with Petrol's substitutes (Alcohol & tobacco, Clothing & footwear, Household energy) and a substitute for Petrol's complements (Health, Recreation & culture, and the Miscellaneous category).

Table 3: Cross-price elasticities: transport goods and other goods

	Prices of other goods on transport				Prices of transport on other goods			
	Uncompensated		Compensated		Uncompensated		Compensated	
	Petrol	Other tp	Petrol	Other tp	Petrol	Other tp	Petrol	Other tp
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Food	-0.510	-0.228	-0.254	0.157	-0.108	-0.026	-0.054	0.045
Alcohol & tobacco	0.223	-0.866	0.261	-0.810	0.311	-1.640	0.380	-1.550
Clothing & footwear	0.675	-1.584	0.711	-1.529	0.975	-3.166	1.074	-3.035
Household energy	0.111	-0.166	0.189	-0.047	0.121	-0.070	0.136	-0.049
Health	-0.644	0.854	-0.608	0.909	-1.003	1.670	-0.913	1.787
Petrol	-0.660	**0.907**	-0.605	**0.990**	-0.660	**1.227**	-0.605	**1.299**
Other transport	**1.227**	-2.257	**1.299**	-2.149	**0.907**	-2.257	**0.990**	-2.149
Recreation & culture	-0.844	1.419	-0.740	1.577	-0.480	0.961	-0.388	1.081
Miscellaneous	-0.446	0.613	-0.254	0.902	-0.133	0.258	-0.072	0.338

Source: Estimated from Household Economic Survey 2006/07, 2009/10, 2012/13, 2015/16, 2018/19

Petrol and Other transport are strong substitutes. Petrol is slightly more elastic with respect to the price of Other transport, than Other transport with respect to the price Petrol. In particular, a 10% increase in the price of Other transport is estimated to increase Petrol demand by 12%, whereas a 10% increase in Petrol price is estimated to increase the demand for Other transport by 9.1%.

For three categories, the price of transport has a larger impact on their demand than the impact of their prices on transport's demand: Alcohol & tobacco, Clothing & footwear, Health. The opposite is true of Food, Recreation & culture, Miscellaneous.

Compensated price elasticities are higher than uncompensated elasticities, which underlies the role of the income effect in defining price elasticity. The patterns of substitutability and complementarity are very similar between the two types of elasticities. The only difference is that Food and Other transport are complements based on uncompensated elasticities (columns 2, 6) but substitutes based on compensated elasticities (column 4, 8).

3.3.2 Robustness checks

The different findings between the current study and the previous study as noted in section 3.3.1 suggest that estimates of elasticities vary markedly across methods, data and expenditure groupings. This section assesses the robustness of our baseline results by examining several alternative specifications, where each specification involves one difference from the baseline specification:

1. Household size is the only demographic control: compared with the baseline specification which controls for seven demographic characteristics, see page 11

2. AIDS instead of QUAIDS: this is equivalent to dropping the last term on the right-hand side of equation (1)
3. Diesel is combined with Petrol: compared with Diesel being in Other transport in the baseline specification
4. Includes Housing and Durables: This means Housing is added to Household energy, Household contents forms an extra category, Vehicle purchase is added to Other transport, and durables items (audio-visual equipment, computing equipment, and major recreational and cultural equipment) are added to Recreation & culture. Thus, this specification has 10 expenditure categories.
5. Recreation & culture and Miscellaneous are combined into one group. Thus, this specification has 8 expenditure categories.
6. Petrol and Other transport combined: Thus, this specification has 8 expenditure categories.
7. Transport is disaggregated into 4 categories: Petrol, Other private transport, Public transport, Air transport. Thus, this specification has 11 expenditure categories.
8. Within transport only: This means m in equation (1) is the total expenditure for transport goods only, instead of total household expenditure for all goods purchased by the household as in the baseline specification. The 4 categories considered are the four transport categories as in specification 7.
9. Air transport is excluded from Other transport: Due to its lumpiness and irregularity, here Air transport is treated as a durable.
10. National prices, 9 expenditure categories: National price indices are used in place of regional price indices. The 9 categories are as in the baseline specification.
11. National prices, 12 expenditure categories: National price indices are used in place of regional price indices. The 12 categories are: Food, Alcohol & tobacco, Clothing & footwear, Housing & household energy, Household contents, Health, Vehicle purchase, Petrol, Other private transport, Public transport, Air transport, and All other.
12. National prices, 18 expenditure categories: National price indices are used in place of regional price indices. The 18 categories are as in Appendix Table 2.

Table 4 presents key estimation results from these 11 specifications. Average estimated elasticities are very similar when household size is the only demographic control (row 1), or when AIDS is used (row 2) instead of QUAIDS. However, having more controls allows elasticities to vary across demographic characteristics, while QUAIDS allows elasticities to vary across income levels. Estimated elasticities for the two transport categories remain similar when Diesel is combined with Petrol (row 3), when Housing and Durables are included, and when Recreation & culture and Miscellaneous are aggregated into one category (row 5).

When Petrol and Other transport are combined (row 6), the median expenditure elasticity for this aggregate transport category is estimated to be 1.13, compared with 0.85 for Petrol and 1.45 for Other transport in the baseline specification. At means, the estimated uncompensated price elasticity for transport is –0.07, compared with –0.66 for Petrol and –2.26 for Other transport. These results indicate that aggregate transport is a borderline luxury/necessity good and is largely not responsive to its own price changes, in contrast with the baseline results which suggest Petrol is a necessity and largely price inelastic, while Other transport is a luxury and very price elastic. These results suggest that high level of expenditure aggregation is likely to mask heterogeneous responses to price changes. Unfortunately, while further disaggregating Other transport (row 7) results in similar elasticities for Petrol, estimates for the other transport categories (Other private transport, Public transport, Air transport; results not shown) are implausible, likely due to the high proportion of households not reporting expenditures on those categories during the survey period.

Table 4: Expenditure elasticities and own-price elasticities under different modelling assumptions

	Median expenditure elasticity		Uncompensated price elasticity		Compensated price elasticity	
	Petrol	Other transport	Petrol	Other transport	Petrol	Other transport
Baseline	**0.846**	**1.446**	**-0.660**	**-2.257**	**-0.605**	**-2.149**
1) Hhd size is the only demog. control	0.852	1.530	-0.649	-2.367	-0.594	-2.254
2) AIDS instead of QUAIDS	0.930	1.398	-0.699	-2.364	-0.641	-2.259
3) Diesel is combined with Petrol	0.856	1.475	-0.577	-2.401	-0.517	-2.298
4) Includes Housing and Durables	0.858	2.028	-0.672	-2.000	-0.636	-1.850
5) Recreation & culture and Miscellaneous are combined	0.835	1.438	-0.597	-2.023	-0.544	-1.917
6) Petrol and Other transport are combined*	1.131		-0.070		0.094	
7) Transport is disaggregated into 4 categories#	0.847		-0.659		-0.604	
8) Within transport only#	0.979		-0.905		-0.470	
9) Air transport is excluded	0.870	0.982	-0.397	-0.621	-0.339	-0.567
10) National prices, 9 exp categories	0.841	1.457	-0.460	-0.635	-0.406	-0.526
11) National prices, 12 exp categories#	0.855		-0.330		-0.294	
12) National prices, 18 exp categories#	0.842		-0.350		-0.314	

Source: Estimated from Household Economic Survey 2006/07, 2009/10, 2012/13, 2015/16, 2018/19

Notes: *Results are for Transport combined, #Other transport is disaggregated into several categories

When only transport expenditures are considered (row 8), Petrol is more elastic to its own price based on uncompensated elasticity (–0.91 vs. –0.66 in baseline), but less elastic based on compensated elasticity (–0.47 vs. –0.61). The different patterns are due to Petrol making up a larger share in total transport expenditure than in total expenditure.

When Air transport is excluded from Other transport (row 9), estimated income and price elasticities change slightly for Petrol but substantially for Other transport: Other transport is now estimated to be a necessity good and price-inelastic. Thus, it is apparent that the estimates for Other transport in the baseline specification are driven by Air transport. Even though we do not model Air transport explicitly, we can infer from this analysis that Air transport is luxury good and the demand for it is price-elastic.

When national prices are used (row 10), estimated median expenditure elasticities are similar to when regional prices are used, yet estimated price elasticities are much lower (in magnitude). In particular, estimated uncompensated price elasticities for Petrol and Other transport are respectively –0.46 and –0.64, compared with –0.66 and –2.26 in the baseline specification. These results are consistent with those in section 4.2, which estimates much lower price elasticities of fuel using aggregate data and with Levin et al.'s (2017) finding that higher levels of temporal and spatial aggregation introduce biases that result in more inelastic demand estimates.

Overall, this section shows that our baseline results are relatively robust to modelling assumptions. Nevertheless, the robustness results highlight the importance of disaggregating expenditures and allowing for geographic price variation in demand system modelling.

3.3.3 Disaggregated results

As noted in section 3.1, QUAIDS models how much a household spends on good i as a function of the relative prices of other goods (to good i), the household's income level and its tastes. Table 5 presents estimated elasticities across income levels and demographic groups (which proxy for tastes).

Moving across the expenditure distribution from the lowest to the highest quintile, expenditure elasticity decreases and own-price elasticity for Petrol decreases (in magnitude). In particular, median expenditure elasticity of Petrol is 1.01 and own-price uncompensated elasticity is –0.78 for the poorest quintile, compared with 0.59 and –0.43 respectively for the richest quintile.

For Other transport, expenditure elasticity decreases slightly across quintiles, but own-price elasticity is markedly lower (in magnitude) for richer quintiles. That is, Petrol is more of a luxury good for poorer households, and these households are more price-elastic (or less price-inelastic) to transport goods' prices. A similar pattern is observed across income quintiles.

The demand for Petrol is more price-inelastic for households that have people aged 65+, Māori, people with at least a Bachelor degree, and households without children. Not much differences in estimated elasticities are seen between migrant and non-migrant households, or across major geographic regions. Overall, the basic patterns hold for all population groups: on average Petrol is a necessity, Other transport is a luxury, the demand for Petrol is price-inelastic and the demand for Other transport is price-elastic.

Cross-elasticities (evaluated at the means) between transport goods and other goods for the poorest and richest expenditure quintiles are shown in Table 6. For both quintiles, Petrol is found to be a substitute for Alcohol & tobacco, Clothing & footwear, and Other transport and a complement to Health, Recreation & culture, and the Miscellaneous category. Household energy is a substitute for Petrol in the poorest quintile, but a complement for Petrol in the richest quintile. By contrast, Food is a complement to Petrol in the poorest quintile, but Food price is estimated to have no effect on the demand for Petrol in the richest quintile. As Other transport is a substitute for Petrol, it is complementary with Petrol's substitutes and a substitute for Petrol's complements.

Table 5: Expenditure elasticities and own-price elasticities for by population groups

	Median expenditure elasticity		Uncompensated price elasticity		Compensated price elasticity	
	Petrol	Other transport	Petrol	Other transport	Petrol	Other transport
Baseline	**0.846**	**1.446**	**-0.660**	**-2.257**	**-0.605**	**-2.149**
Expenditure quintile						
1 (poorest)	1.008	1.338	-0.783	-2.891	-0.721	-2.818
2	0.948	1.426	-0.752	-2.435	-0.682	-2.340
3	0.865	1.486	-0.685	-2.230	-0.624	-2.120
4	0.761	1.493	-0.597	-2.062	-0.549	-1.935
5 (richest)	0.589	1.481	-0.429	-1.919	-0.400	-1.775
Income quintile						
1 (poorest)	0.970	1.407	-0.725	-2.725	-0.667	-2.644
2	0.922	1.434	-0.721	-2.383	-0.657	-2.284
3	0.868	1.448	-0.692	-2.216	-0.631	-2.105
4	0.796	1.481	-0.639	-2.130	-0.585	-2.010
5 (richest)	0.641	1.452	-0.477	-1.966	-0.443	-1.828
Has child in household						
No	0.835	1.438	-0.627	-2.210	-0.575	-2.098
Yes	0.871	1.470	-0.717	-2.375	-0.655	-2.274
Has people aged 65+ in household						
No	0.839	1.420	-0.688	-2.204	-0.630	-2.093
Yes	0.868	1.524	-0.559	-2.408	-0.513	-2.307
Has Māori in household						
No	0.825	1.459	-0.631	-2.214	-0.579	-2.102
Yes	0.937	1.379	-0.791	-2.547	-0.720	-2.458
Has migrant in household						
No	0.864	1.483	-0.662	-2.421	-0.608	-2.321
Yes	0.815	1.378	-0.655	-2.019	-0.601	-1.895
At least 1 hhd member has a Bachelor						
No	0.893	1.456	-0.707	-2.456	-0.647	-2.359
Yes	0.736	1.425	-0.552	-1.950	-0.509	-1.815
Household composition						
Couples only	0.787	1.455	-0.562	-2.060	-0.517	-1.933
Couples with child(ren)	0.813	1.463	-0.666	-2.215	-0.611	-2.102
One-person households	0.919	1.446	-0.630	-2.479	-0.579	-2.384
Other household	0.905	1.408	-0.757	-2.418	-0.688	-2.321
Rural/urban sector						
Rural	0.871	1.390	-0.737	-2.211	-0.671	-2.102
Other urban	0.873	1.497	-0.667	-2.421	-0.611	-2.322
Major urban	0.820	1.426	-0.637	-2.164	-0.585	-2.049
Broad region						
Auckland	0.855	1.414	-0.673	-2.175	-0.612	-2.063
Wellington	0.747	1.461	-0.580	-2.187	-0.540	-2.070
Rest of North Island	0.884	1.457	-0.688	-2.361	-0.629	-2.261
Canterbury	0.836	1.456	-0.637	-2.243	-0.587	-2.133
Rest of South Island	0.843	1.456	-0.667	-2.300	-0.614	-2.193

Source: Estimated from Household Economic Survey 2006/07, 2009/10, 2012/13, 2015/16, 2018/19

Table 6: Uncompensated cross-price elasticities: transport goods and other goods, expenditure quintiles 1 and 5

	Expenditure quintile 1				Expenditure quintile 5			
	Prices of other goods on transport		Prices of transport on other goods		Prices of other goods on transport		Prices of transport on other goods	
	Petrol	Other tp	Petrol	Other tp	Petrol	Other tp	Petrol	Other tp
Food	-1.135	0.176	-0.197	0.047	-0.093	-0.426	-0.023	-0.095
Alcohol & tobacco	0.150	-1.116	0.180	-1.526	0.367	-0.723	0.486	-1.938
Clothing & footwear	0.834	-2.270	2.062	-6.262	0.760	-1.210	0.594	-2.068
Household energy	0.507	-0.571	0.227	-0.165	-0.228	0.043	-0.233	0.193
Health	-0.738	1.182	-0.942	1.603	-0.772	0.671	-1.004	1.635
Petrol	-0.783	**1.428**	-0.783	**1.553**	-0.429	**0.626**	-0.429	**1.342**
Other transport	**1.553**	-2.891	**1.428**	-2.891	**1.342**	-1.919	**0.626**	-1.919
Recreation & culture	-0.862	1.865	-0.504	1.124	-1.098	1.160	-0.432	0.793
Miscellaneous	-0.652	0.973	-0.155	0.276	-0.398	0.417	-0.112	0.238

Source: Estimated from Household Economic Survey 2006/07, 2009/10, 2012/13, 2015/16, 2018/19

3.3.4 Summary

Using household-level data, we estimate that price elasticity of petrol demand is –0.66, ranging from –0.78 for the lowest expenditure quintile to –0.43 for the highest expenditure quintile, indicating that petrol demand is price-inelastic, and more so for richer households. These estimates are in the range of around –0.2 to –1.1 estimated by studies using household- or individual-level survey data documented in section 2.1. The estimated median expenditure elasticity for petrol is 0.85, suggesting that petrol is a necessity good. Other transport is estimated to be a luxury and the demand for it is price-elastic.

In general, petrol is found to be a substitute for Alcohol & tobacco, Clothing & footwear and Other transport and complementary with Health, Recreation & culture, and the Miscellaneous category. Cross-elasticities between petrol and Food and Household energy vary across the expenditure distribution. Being petrol's substitute, Other transport is complementary with petrol's substitutes and a substitute for petrol's complements.

4 Time-series analysis – Elasticities of fuel consumption

4.1 Analytical approach

In this section, we document the estimation of own-price elasticities of fuel demand, using time-series variation. The demand for fuel is modelled as a function of the (real) fuel price, allowing for a contemporaneous and lagged effect. Our initial specification is similar the estimation approach of Kennedy and Wallis (2007 - eq 1a).[19]

$$\ln Fuel_t = \alpha + e_0 \ln P_t^F + \sum_k \left(e_k \ln P_{t-k}^F\right) + \beta_0 \ln D_t + \sum_k (\beta_k \ln D_{t-k}) + \varepsilon_t \quad (5)$$

To address the standard challenges of identifying demand elasticities (Berry & Haile, 2021) a demand shifter (D_t) is included, captured by the log of real GDP. Fuel consumption and GDP are measured in *per capita* terms. The model is specified in logs, so that the price coefficients can be interpreted as elasticities (the proportional impact on demand of a proportional change in price). The main parameters of interest in equation (5) are the elasticities of fuel consumption $(e_0$ and $e_k)$ with respect to the real price of fuel (P_t^F). The coefficient e_0 captures the short-run elasticity, and the sum of coefficients $(e_0 + \sum e_k)$ captures the long-run elasticity. Similarly, the short-run income elasticity of demand is captured by β_0, with the long-run elasticity calculated as $(\beta_0 + \sum \beta_k)$.

Kennedy and Wallis (2007) use quarterly data and include a 4-quarter seasonal lag (k=4) of price, but no lags of GDP. Because the series are non-stationary, they estimate the equation in differenced form, transforming equation (5) using a 4-quarter seasonal difference $(\Delta_4 X_t = X_t - X_{t-4})$ to minimise bias due to autocorrelation, and thus avoid the risk of spurious regression. We compare estimates from the Kennedy and Wallis specification, using updated data, with a distributed lag model estimated in first-differenced data $(\Delta X_t = X_t - X_{t-1})$ and including a series of quarterly lags. We also use an instrumental variables (IV) approach, using Australian fuel prices as an instrument for P_t^F, on the assumption that it is uncorrelated with unobserved demand variation in New Zealand but correlated with New Zealand fuel prices. We re-estimate the equation within a vector autoregression framework to identify separately the short-run and long-run elasticities. Finally, we allow for the price elasticity of demand to vary with the price level.

4.2 Data sources

As summarised in Table 7, the data for the time-series analyses are all publicly available. Fuel consumption data are from MBIE's Oil Statistics table, which contains data for oil production, transformation and consumption in New Zealand. These data do not distinguish between consumption by households versus consumption by non-households. Thus, we restrict our analysis to petrol consumption to keep the focus on the household sector. We use total quarterly consumption of regular and premium petrol from Agriculture, forestry and fishing, Industrial, Commercial and Public Services, Residential, and Domestic land transport. In 2019, these components respectively account for 1.39%, 0.08%, 0.56%, 11.87% and 86.11% of our total consumption measure. Given

[19] Kennedy & Wallis (2007) also estimate petrol price elasticities of weekly traffic volumes and quarterly public transport patronage. We tried estimating VKT elasticity but obtained small and insignificant long-run elasticity estimates. This is likely because the available VKT data only cover 2010–-2021, which means that we effectively have only 10 years of data (allowing for lagged changes).

that diesel is the primary fuel used for commercial land transport and petrol consumption tends to be for private land transport, we can infer that households' share in our total petrol consumption measure is equal to the total share of domestic land transport and residential, which ranges from 85% to 99% in each year during the study period.

Table 7: Data sources for time-series analysis

Series	Frequency	Time span	Source
Petrol consumption (millions of barrels)	National, Annual & Quarterly	1974–2022	MBIE[a]
Petrol price (cents/litre)	National, Annual & Quarterly	1974–2022	MBIE[b]
GDP (Expenditure)	National, Quarterly, Seasonally adjusted	1987–2022	SNZ[c]
GDP (Production)	National, Quarterly. Seasonally adjusted	1974–2022	Hall & McDermott (2007)[d]
Population	National, Quarterly	1951–2022	SNZ[e]
Australian fuel price (index value)	National, Quarterly	1972–2021	ABS[f]

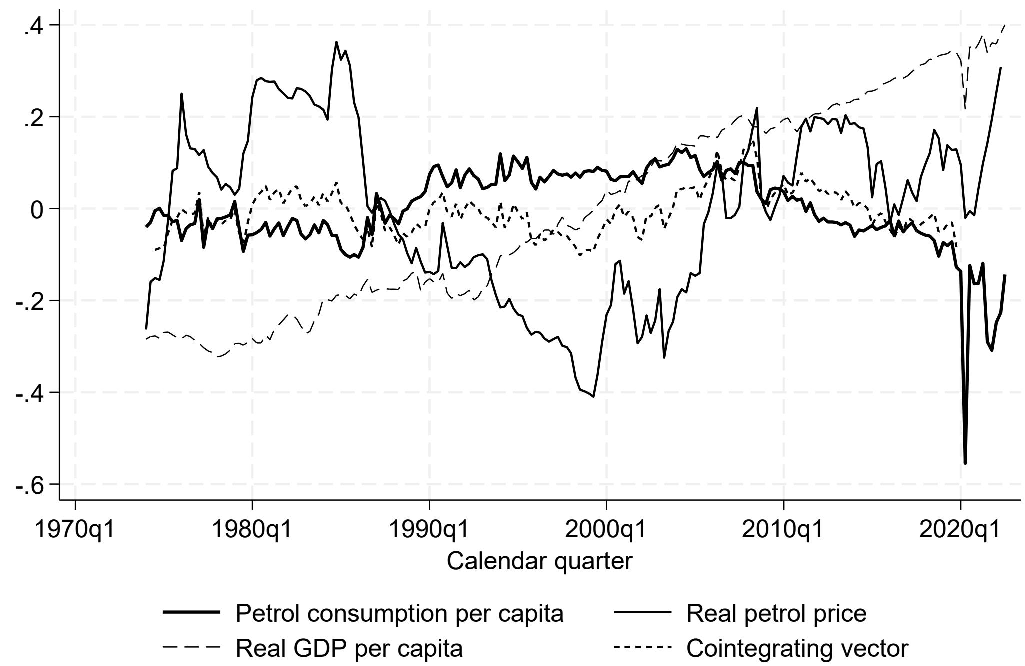
Sources:

- [a]Total petrol consumption. Oil statistics, https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-statistics-and-modelling/energy-statistics/oil-statistics/, accessed 19 December 2022
- [b]Real petrol price (c/litre, sales weighted average of regular and premium prices): Energy prices, https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-statistics-and-modelling/energy-statistics/energy-prices/, accessed 14 November 2022
- [c]GDP(E), Chain volume, Seasonally adjusted, Total (Qrtly-Mar/Jun/Sep/Dec) available from infoshare.stats.govt.nz (Table Ref: SNE021AA. Series identifier: SNEQ.SG02RSC00B15)
- [d]Used for 1974q1-1987q1. Backcast seasonally adjusted GDP (Production): scaled to align with GDP(E) in 1987q2 (updated series available from https://www.motu.nz/our-research/wellbeing-and-macroeconomics/economic-performance/a-quarterly-post-world-war-ii-real-gdp-series-for-new-zealand/)
- [e]Estimated Resident Population, available from infoshare.stats.govt.nz, Table 'Estimated Resident Population (Mean Quarter Ended) by Sex (1991+) (Qrtly-Mar/Jun/Sep/Dec)'
- [f]Australian Bureau of Statistics, Automotive fuel in the CPI 23/03/2021, https://www.abs.gov.au/articles/automotive-fuel-cpi

Fuel prices are from the Ministry of Business, Innovation and Employment (MBIE)'s Energy Prices database, which contains price data on petrol, diesel, fuel oil, natural gas and electricity. We use the quarterly total price of petrol which is a sales-weighted average of the regular and premium petrol prices for all of New Zealand. MBIE constructs real price using Statistics New Zealand's Consumers Price Index series - CPIQ:SE9A.

GDP data are seasonally adjusted real GDP Expenditure measure, available from Statistics New Zealand's infoshare.stats.govt.nz, augmented with historical GDP Production data from Hall & McDermott (2007). To calculate per capita (GDP, petrol consumption) measures, we use Statistics New Zealand's estimated resident population data. Australian real fuel price is calculated by deflating Australia's quarterly fuel price index by its CPI, where the underlying indices are compiled by Australian Bureau of Statistics.

Figure 1 summarises the time-series variation in the key series used for estimation. All series are in logs and, for the purposes of graphing, each is measured relative to its mean. Real GDP per capita has a clear upward trend and there appears to be a negative relationship between petrol prices and petrol consumption per capita. Consumption is highest between 1990 and 2005, when real prices were relatively low. There is a substantial one-quarter drop in consumption in 2020q2, related to the Covid lockdown period that started in March 2020. We restrict our estimation period to end in 2019 on the basis that the 2020 changes are not informative about demand elasticities – the changes in consumption were clearly related to factors other than price variation.



Notes: All series are seasonally adjusted and each is measured relative to its mean value.

Figure 1: Time-series variation in petrol price, petrol consumption per capita and real GDP per capita

4.3 Times-series results

4.3.1 Baseline results

Table 8 contains estimation results from the time-series analysis. Following Kennedy and Wallis (2007), we calculate season-to-season annual difference (denoted S4 in Table 8), which is the difference between variables in one quarter of a year and the same quarter in the preceding year.

Table 8: Estimation results from time-series analysis

Dependent variable: ln(Petrol)		Kennedy-Wallis (1978-2006) (1)	Kennedy-Wallis (1978-2019) (2)	Distributed lag (1978-2019) (3)	Distributed lag (AR adj) (1978-2019) (4)	Distributed lag (IV*) (1978-2019) (5)
Transform		S4	S4	S1	S1	S1
ln(price)	S	-0.130***	-0.105***	-0.114**	-0.0910*	-0.0473
		(0.0316)	(0.0273)	(0.0345)	(0.0398)	(0.0541)
	LS			0.0292	0.0221	-0.0568
				(0.0304)	(0.0328)	(0.0565)
	L2S			-0.0884*	-0.0885*	-0.0199
				(0.0348)	(0.0359)	(0.0733)
	L3S			-0.0343	-0.0275	-0.166*
				(0.0399)	(0.0403)	(0.0835)
	L4S	-0.0432	-0.0690*	0.0227	0.00147	0.0852
		(0.0354)	(0.0303)	(0.0441)	(0.0372)	(0.0727)
ln(GDPpc)	S	0.246*	0.307**	0.389*	0.380*	0.317
		(0.109)	(0.109)	(0.159)	(0.147)	(0.168)
	LS			-0.197	-0.202	-0.170
				(0.185)	(0.151)	(0.185)
	L2S			0.0245	0.0160	-0.0460
				(0.185)	(0.182)	(0.198)
	L3S			0.247	0.223	0.284
				(0.167)	(0.174)	(0.179)
	L4S	-0.162	-0.153	-0.268	-0.273*	-0.324*
		(0.114)	(0.105)	(0.142)	(0.135)	(0.161)
N quarters		124	176	179	179	179
R-sq		0.212	0.197	0.180	0.177	0.080
Adj. R-sq		0.185	0.178	0.131	0.128	0.025
LR Price		-0.173***	-0.174***	-0.185*	-0.183**	-0.205
		(0.046)	(0.041)	(0.088)	(0.061)	(0.126)
LR GDP		0.0837	0.154	0.196	0.143	0.0618
		(0.168)	(0.160)	(0.458)	(0.310)	(0.480)

Notes:

- Dependent variable is log petrol consumption per capita
- Sq = X_t-X_{t-q} where X is the variable of interest, t indexes quarter, see text for detail
- LzS is z-quarter lag of Sq
- Robust standard errors in parentheses. * p<0.05, ** p<0.01, *** p<0.001
- IV stats: UnderID (Anderson CanCorr = 20.9, p-value=0.00); weakID (Cragg-Donald Wald F = 8.4)

The explanatory variables are ‘differenced’ in the same manner. The 4-quarter lags (L4) of differences in price levels are added to capture long-run impacts of prices. Our initial model in

Column (1) is close to Kennedy and Wallis's (2007) model 1a,[20] which is their preferred specification on the basis that it produces highly significant coefficients and plausible results. The estimates in column (1) are for the same time period that Kennedy and Wallis's study covered (1978–2006).

The coefficient on the season-to-season annual difference in log petrol price can be interpreted as short-run (0-1 year) price elasticity (–0.130), the corresponding coefficient on lagged difference (-0.043) can be interpreted as interim (1-2 years) price elasticity while the sum of both coefficients can be interpreted as medium-run (0-2 years) or long-run (3+ years) price elasticity. The implied long-run price elasticities (LR Price), income elasticities (LR GDP) and associated standard errors are shown at the bottom of the table. For the same sample period as used by Kennedy and Wallis (2007), we estimate a statistically significant long-run price elasticity of –0.17, compared with their estimate of –0.23, and an insignificant 0.08 income elasticity, smaller than their (significant) estimate of 0.35. This difference in income elasticities reflects a negative lagged effect that offsets the strong positive contemporaneous income effect.

The second column of Table 8 extends the sample period to 2019q4. The long-run price elasticity of demand is almost identical, and the income elasticity remains insignificantly different from zero, though somewhat larger, at 0.15. In the third column of Table 8, we report estimates based on one-quarter differences, and include 4 quarterly seasonal lags of both price and income. The magnitude of the estimated long-run price elasticity increases slightly, to –0.185, and the income elasticity to 0.196. The short-run price elasticity (–0.114) is weaker than the long-run elasticity, indicating a lagged response of demand to price changes. For the income elasticity, lagged effects offset the strong short-run elasticity (0.389), though the income elasticity estimates are imprecisely estimated. The long-run elasticities in column (3) are our preferred central estimates – a long-run price elasticity of demand for petrol of –0.185 and a long-run income elasticity of demand for petrol of 0.196. We test the robustness of these findings in columns (4) and (5) of Table 8.

A Durbin-Watson alternative test for autocorrelation of the residuals from column (3) rejects the hypothesis of no autocorrelation at the 1% significance level, implying that the standard error estimates are biased. Column (4) re-estimates the distributed lag model of column 3, using the Prais-Winsten method.[21] The corrected estimates are largely unchanged, with only moderate impact on the estimated standard errors. The final column of Table 8 tests the robustness of our findings to controls for potential endogeneity, which can arise if petrol price is correlated with unobserved factors influencing the demand for petrol. For example, an increase in the petrol excise duty can increase the demand for electric vehicles, lowering the demand for petrol (an inward shift of the demand curve) and further dampening the effect of a higher petrol price on the quantity of petrol demanded (a movement along the demand curve). This would lead to a bias in the estimated price elasticity of demand. We adopt an IV approach, using Australian petrol prices as an instrument for New Zealand prices. The rationale for this instrument is the Australian petrol price and New Zealand petrol price are highly correlated with each other (and with world oil price), yet Australian petrol price is unlikely to be correlated with unobserved demand variation in New Zealand. The estimates in column (5) do, indeed, show a slightly stronger negative price elasticity (–0.205), but the greater impact is on the

---

[20] Kennedy & Wallis (2007) do not include a lagged difference of ln(GDP). We include it to allow for lagged income effects. This has no appreciable effect on the estimated long-run price elasticity but does change the estimated income elasticity. We use seasonally adjusted series, whereas Kennedy & Wallis (2007) use unadjusted series and include seasonal dummies.

[21] The estimated autocorrelation coefficient is $\rho = -0.35$. The Prais Winsten transformation reduces the Durbin-Watson statistic from 2.63 (indicating negative autocorrelation) to 2.06. This is still above the relevant 5% significance upper bound of around 1.9 for DW(11,179) implied by Savin and White (1977), indicating that negative autocorrelation has not been completely removed.

precision of the estimates, resulting in larger standard errors and statistically insignificant estimates. We maintain the estimates in the third column as our preferred estimates, on the basis that the potential problems of autocorrelation and endogeneity do not appear to be greatly biasing those estimates.

In summary, we find that for the period 1978–2019, the short-run price elasticity of aggregate petrol consumption tends to be small, (–0.114), while the long-run elasticity is about –0.185. These results indicate that at the aggregate level, petrol demand is very price-inelastic, and more so in the short run than in the longer run. These estimates are well within the range of around –0.03 to –0.3 estimated by studies using aggregate data as documented in section 2.1. Even though our longer-run results are similar to those estimated by Kennedy and Wallis (2007) for the period 1978–2006, their short-run elasticities are only slightly smaller than longer-run elasticities. We find a smaller income elasticity (with respect to GDP per capita) than was found by Kennedy and Wallis (2007). Our estimate is based on a specification that includes lagged effects, which were not included by Kennedy and Wallis (2007). Our estimate is 0.196 and is statistically insignificant, compared with their significant estimate of around 0.3. Using GDP per capita as a proxy for income, this estimate indicates that petrol is a necessity good.

4.3.2 Robustness checks

Vector Error Correction model

The estimates presented so far have transformed the variables in equation (5) by differencing them, to avoid the problems that arise when the underlying series are autocorrelated. An alternative approach is to simultaneously estimate the long-term relationship between (undifferenced) variables, and the dynamic adjustments. Where the variables are cointegrated, this can be done using a Vector Error Correction (VEC) model.

Cointegrating equation: $CE_t = \alpha + c_1 \ln Fuel_t + c_2 \ln P_t^F + c_3 \ln D_t$

Error correction equations:

$$\begin{aligned} \Delta \ln Fuel_t &= \alpha_1 + d_{11}\mathrm{CE}_{t-1} + \mathrm{d}_{12}\Delta \ln Fuel_{t-1} + \mathrm{d}_{13}\Delta \ln P_{t-1}^F + d_{14}\Delta \ln D_{t-1} + u_{1t} \\ \Delta \ln P_t^F &= \alpha_2 + d_{21}\mathrm{CE}_{t-1} + \mathrm{d}_{22}\Delta \ln Fuel_{t-1} + \mathrm{d}_{23}\Delta \ln P_{t-1}^F + d_{24}\Delta \ln D_{t-1} + u_{2t} \\ \Delta \ln D_t &= \alpha_3 + d_{31}\mathrm{CE}_{t-1} + \mathrm{d}_{32}\Delta \ln Fuel_{t-1} + \mathrm{d}_{33}\Delta \ln P_{t-1}^F + d_{34}\Delta \ln D_{t-1} + u_{3t} \end{aligned} \quad (6)$$

The price elasticity of demand within the VEC framework has two components – first, there is a change in fuel consumption in response to the price change (d_{13}). Furthermore, the price change perturbs the long-run relationship, so there is also a response (of all variables) to correct this 'error' (d_{11}, d_{21}, d_{31}).

Appendix Table 4 reports the estimated coefficients for this VEC model.[22] The estimated cointegrating equation is plotted in Figure 1, as estimated for the period 1978–2019. The price and income elasticities of demand cannot be read directly from the coefficients of the model. Instead, the

[22] Formal econometric tests identify one cointegrating equation (HQIC statistic) or no cointegrating equations (Trace or SBIC statistics). The lag order of the underlying VAR is identified as 2 (FPE and AIC statistics), implying that a single lag is appropriate for the VEC specification.

dynamic responses of petrol consumption to a change in price and in GDP are summarised by the 'impulse-response functions' shown in Figure 2. Panel (a) shows the response of ln(Fuel) to ln(price). The reduction in demand grows over time, gradually converging to a long-run elasticity of –0.344 after 48 quarters (12 years). Panel (b) shows the path of petrol demand changes in response to a change in ln(GDP). An initial decline in petrol demand is reversed in the long run, converging to a long-run elasticity of –0.077.

The estimated long-run price elasticity is stronger than the estimates shown in Table 8, and the estimated income elasticity is weaker. The VEC estimates capture a fuller set of dynamic interactions between the variables, and are thus measuring not only the behavioural demand response to a change in price, but the evolution of all three variables (price, quantity, and income) together. The estimates in Table 8 come closer to matching the behavioural effect on petrol demand of marginal changes to prices and income.

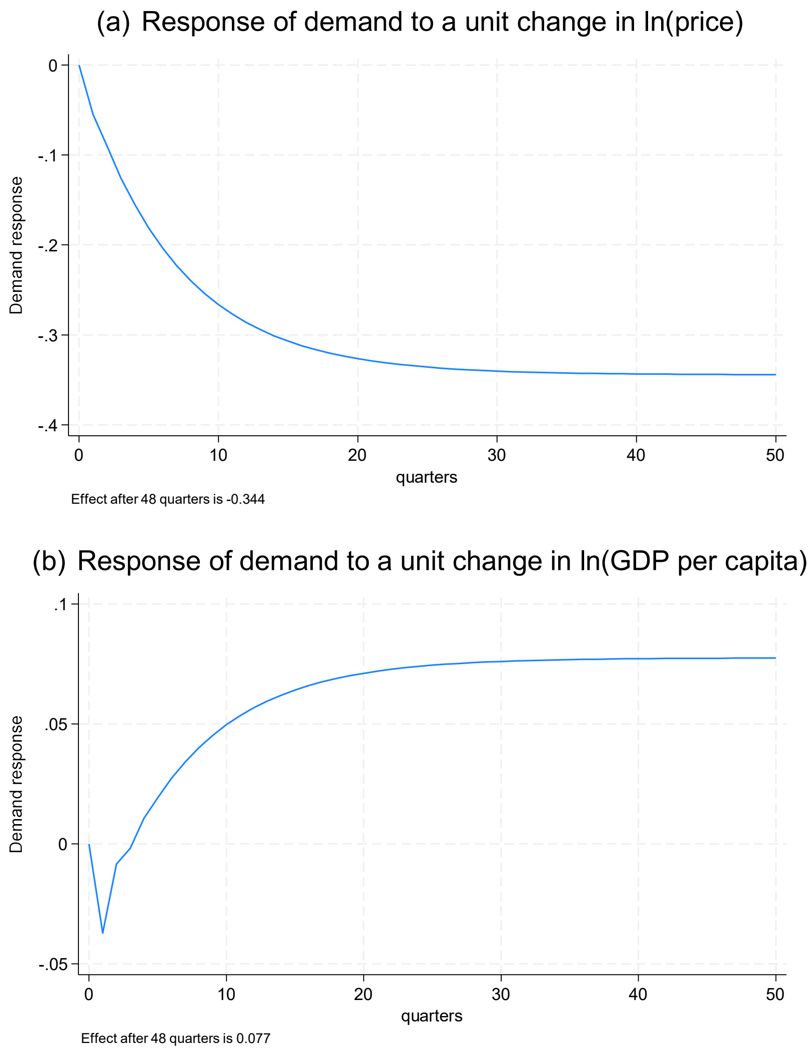
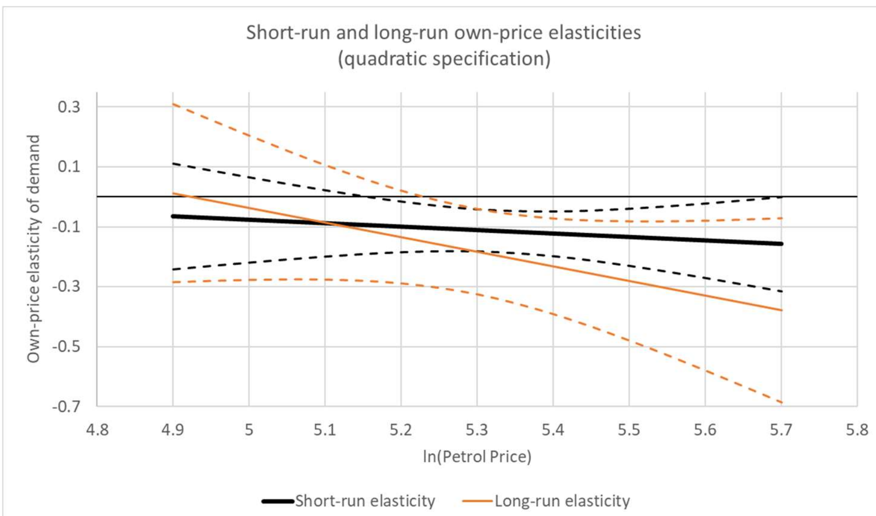


Figure 2: Impulse response functions from Vector Error Correction model

Non-constant price elasticity

All of the estimates presented in this section so far have endeavoured to identify a single value for the price elasticity. Our final robustness check is to investigate whether the response of demand to a change in price depends on the price level. When prices are high, consumers may be more sensitive to price changes because they account for a higher proportion of expenditure. We re-estimate the specification reported in column 3 of Table 8, but adding quadratic price terms to allow for a non-constant price elasticity of demand. The coefficient estimates are shown in Appendix Table 5, and the implied patterns of short-run and long-run elasticities are summarised in Figure 3. Both the short-run and long-run elasticities are larger in magnitude (larger negative values) when the price is higher, and the long-run elasticity is greater than the short-run elasticity at higher prices. However, the non-linear relationship is not very precisely estimated, leading to large confidence intervals around the central estimates. While the estimates do suggest greater elasticities at higher price levels, we cannot reject the hypothesis of constant elasticity.[23]



Notes: Estimates are based on a distributed lag model with quadratic price effects, see Appendix Table 5. Dashed lines indicate 95% confidence intervals around each line.

Figure 3: Non-constant elasticity of demand

Methodologically, this section highlights the sensitivity of elasticity estimates to different specifications and assumptions. Nevertheless, the range of estimates for the price elasticity of demand (–0.17 to –0.34) and the income elasticity of demand (0.08 to 0.20) are consistent in showing that petrol demand is relatively inelastic, and that petrol is a necessity. Our preferred estimates are those in column 3 of Table 8, showing a (constant) long-run price elasticity of –0.185 and a long-run income elasticity of 0.196.

[23] Appendix Table 5 also presents estimates from an IV specification of the same equation but the specification suffers from weak instruments and has extremely large standard errors on the estimated coefficients.

5 Event study – Retail sales and the regional fuel tax

5.1 Background

An alternative approach to identifying fuel own-price elasticities is to examine changes in fuel-retail sales volumes around the time that the ARFT was introduced. A tax of 10c per litre was introduced on 1 July 2018,[24] and applied to all fuel sold within the Auckland region. With the addition of GST, the impact on the price of all grades of petrol and of diesel was 11.5c per litre.[25]

Table 9 shows the initial impact of the ARFT, by type of fuel. The tax raised prices by 6.6% on average, with the proportional increase greatest for diesel (8.3%) and lowest for 98-octane petrol (5.1%). The increased price is expected to lead to a reduction in the quantity of fuel demanded. The strength of the reduction will be used to estimate the fuel demand elasticity.

Table 9: Auckland fuel price (2018q2)

Fuel type	National consumption $share_{2018q2}$	$Price_{2018q2}$ (cents)	$Price_{2018q2}$ *(1+tax)	Implied % change in price	$Price_{2018q3}$ (cents)
Petrol 91	0.363	207.9	219.4	5.5%	225.4
Petrol 95	0.107	222.9	234.4	5.2%	240.4
Petrol 98		226.9	238.4	5.1%	244.4
Diesel	0.530	138.9	150.4	8.3%	156.8
Composite Price*		173.1	184.6	6.6%	190.6

Notes: Price data (GST-inclusive) from https://www.nzta.govt.nz/resources/regional-fuel-tax-quarterly-reports.
National consumption share data are from MBIE Oil data tables (quarterly mmbls) https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-statistics-and-modelling/energy-statistics/oil-statistics/.
*: Composite price is constructed as a weighted average of type-specific prices, using quarter-specific national consumption shares.

The fact that the fuel tax was regionally based has implications for the price elasticity of demand. For at least some purchasers, fuel in neighbouring regions may be a close substitute for fuel bought in Auckland. The *local* price elasticity may therefore be greater than the overall price elasticity of demand because Auckland residents and businesses have the option of reducing their purchases of fuel in Auckland while maintaining their total fuel consumption. In contrast to a national fuel price change, a regional change is also more likely to induce a change in fuel supply – fuel retailers may expand or relocate outlets to nearby lower-price regions.

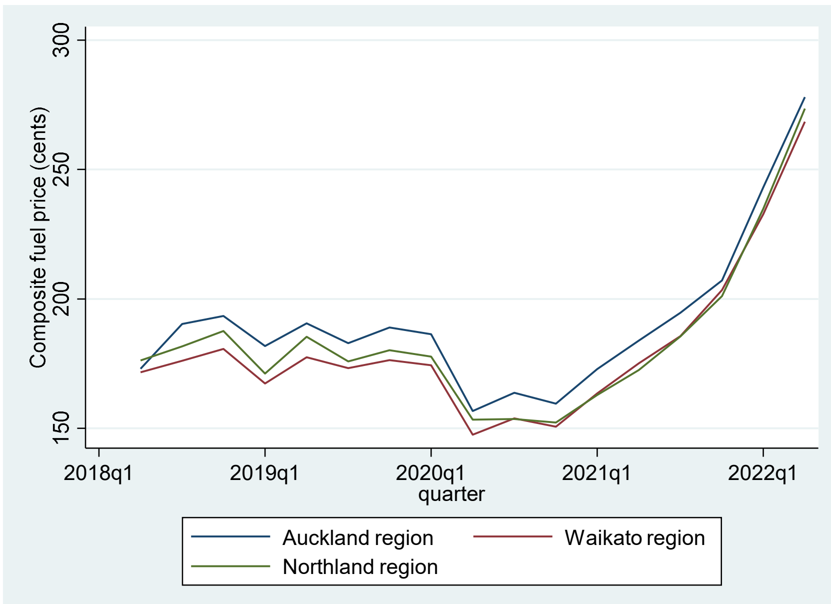
In a market study of the fuel-retail sector, the New Zealand Commerce Commission (2019, p506) estimate that the ARFT was fully passed on to prices. Figure 4 illustrates this pattern using composite

---

[24] Discussion of a regional fuel tax for Auckland predates its introduction. A proposed regional fuel tax was a key plank in Auckland mayor Phil Goff's 2016 election campaign but became feasible only in 2018. The legislation to enable the tax (The Land Transport Management (Regional Fuel Tax) Amendment Bill) was published on 9 March 2018 and introduced in Parliament on 22 March 2018 [https://www.beehive.govt.nz/release/regional-fuel-tax-auckland-step-closer]. The policy was provisionally approved by the Auckland Council on 1 May 2018, with public consultation invited by 15 May 2018 [https://www.driven.co.nz/news/auckland-regional-fuel-tax-approved-for-public-consultation/].

[25] The ARFT is applied at the pump so all purchasers pay the tax at the point of purchase. However, rebates can be claimed for petrol used in commercial use of off-road vehicles, machinery and vessels and private use in personal home heating, see https://www.nzta.govt.nz/vehicles/regional-fuel-tax/how-to-get-started.

fuel price levels, constructed as a weighted average of regional fuel-type-specific prices, from the second quarter of 2018 – just prior to the introduction of the ARFT.[26] Initially, the fuel price in Auckland was between the prices in Waikato and Northland. From 2018q3, Auckland fuel prices were above those in both Waikato and Northland, and remained higher through until at least 2022. By 2022q2, fuel prices had risen markedly, so that the 10c ARFT was a smaller proportion of the overall price (4.1%). For most of the study period, the composite fuel price was between $1.50 and $2.00, implying that the ARFT added between 6% and 8% to Auckland fuel prices.



Note: Composite prices are constructed as a weighted average of fuel-type-specific prices, using quarter-specific national consumption shares, see notes to Table 9.

Figure 4: Composite fuel prices in Auckland, Waikato and Northland regions

Figure 5 confirms that the price premium of around 10 cents in Auckland was evident for all fuel types. Although the regional price differences for each fuel type are fairly volatile, the differences are generally in the 5c to 15c range (apart from the Northland-Auckland price difference from 98 octane petrol), with some evidence of price convergence for petrol in early 2022.

Our analysis of the impact of the ARFT on fuel sales will focus on sales from fuel outlets in Auckland and in the neighbouring regions of Northland and Waikato. Figure 6 shows the location of fuel outlets in these regions, identified from publicly available data.[27] There is a high density of outlets within the Auckland region. NZTA (2018) identifies 309 service stations operating within the Auckland region

[26] Composite prices are constructed as a weighted average of fuel-type-specific prices, using quarter-specific national consumption shares. Unfortunately, regional price data are not available for earlier quarters.

[27] The data used in Figure 6 are not from the same source as is used for our empirical analysis. The data were downloaded on 30 November 2022, so do not represent the locations of outlets throughout our study period.

in October 2018. The degree to which purchasers respond to the higher Auckland fuel price by purchasing fuel in neighbouring regions will depend on the presence of fuel retailers close to the regional boundary, of which there are relatively few.

Figure 7 provides a closer view of outlets around the Auckland regional boundaries with Northland to the North and Waikato to the South. Within a 30km radius of main roads on the Auckland region boundary, there are 31 Auckland outlets, and 14 non-Auckland outlets. While there is certainly scope for cross-border purchasing, the majority of Auckland outlets are sufficiently far from the border. In our empirical analysis, we test the sensitivity of our findings to controls for border proximity.

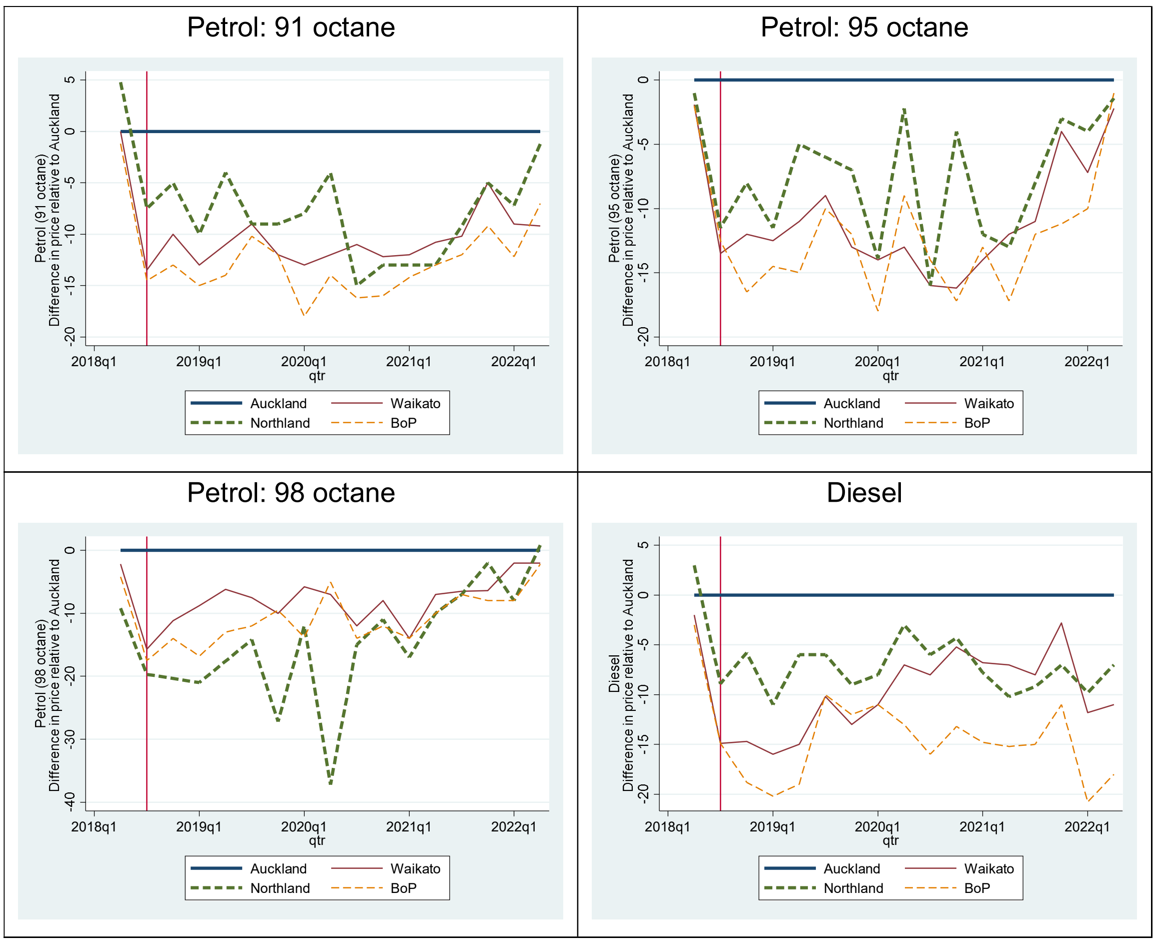
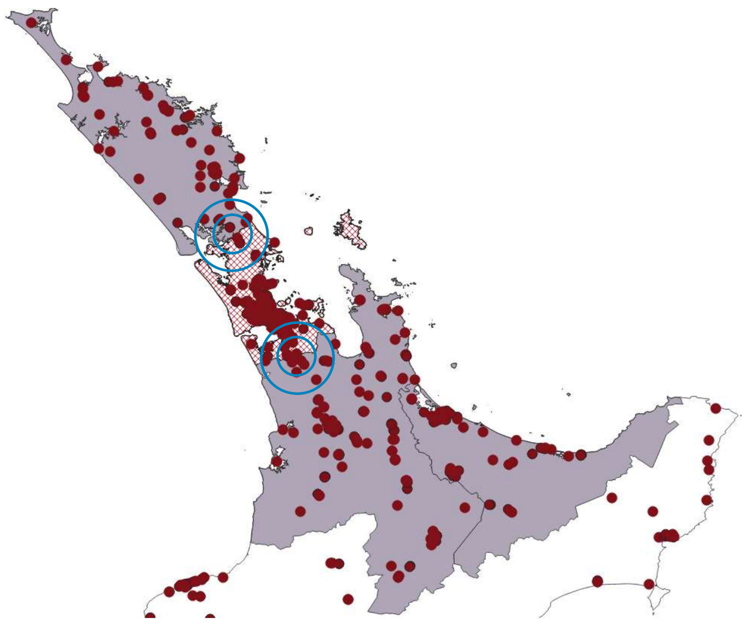


Figure 5: Fuel prices (relative to Auckland)

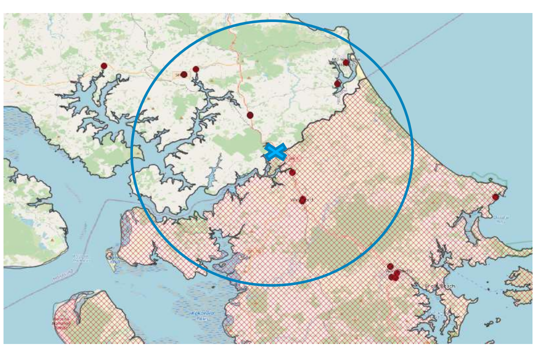


Notes:

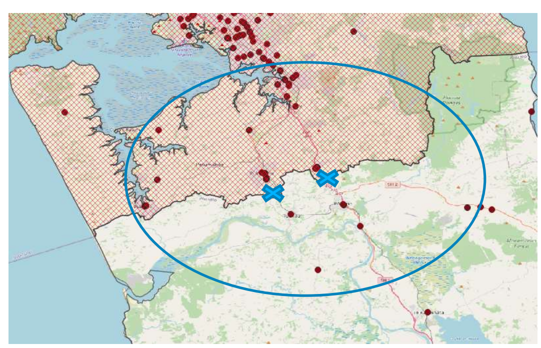
- Gray shaded areas are Northland, Waikato, and Bay of Plenty regions. Auckland is the cross-hatched area, with circles highlighting the main road connections between Auckland and other regions.
- The fuel sites on this map are identified from publicly available data on all sites that accept NZ Fuel Cards (Z Energy (Z Business), BP Fuelcard, Caltex and Challenge (Z Business), and Mobilcard) [https://www.google.com/maps/d/viewer?mid=18MzsaZ2FFyICA3IW6I9THP8VLx4&ll=-40.36539188892598%2C172.98913374999995&z=5, downloaded 30 Nov 2022]. They may differ from the sites used in the study, which uses confidentialised microdata.

Figure 6: Fuel outlets in the Auckland region and neighbouring regions

Northern boundary



Southern boundary



Note: The encircled areas show locations that are within approximately 30km of major road routes out of the Auckland region (marked by X).

Figure 7: Fuel outlets close to Auckland region boundaries

5.2 Data sources

We use business data contained in the Statistics New Zealand Longitudinal Business Database (LBD) and Integrated Data Infrastructure (IDI). These data are anonymised and confidentialised and have been analysed with a secure data lab environment. The main analysis uses firm-level GST (goods and services tax) sales information, linked to the location of fuel-retail outlets.

The linking is imperfect. GST returns in the LBD are associated with a confidentialised identifier based on IRD tax numbers, each of which may relate to one or more enterprises.[28] Consequently, GST returns from fuel retailers may thus reflect sales for a mix of fuel-retail outlets and other activities. Ideally, we would be able to separately identify fuel-retail sales for outlets in the Auckland region, and separately for the outlets in the neighbouring regions of Northland and Waikato. This is possible for only a subset of fuel retailers – those with GST returns that relate to activities in a single region only.

Our analysis must thus be restricted to a subset of data defined by industry scope and geographic scope. The industry scope is based on the industry classification of the firms reporting GST sales. We focus on Australian and New Zealand Standard Industrial Classification (ANZSIC) industry G40: Fuel Retailing. Separate industry coding is available for business sites ('outlets', identified by Permanent Business Numbers (PBNs) in Business data, and for enterprises, which may contain multiple outlets and activities). Industry coding may differ for PBNs and the enterprises to which they belong. We focus on fuel-retail PBNs that belong to fuel-retail enterprises. This excludes fuel-retail sites belonging to enterprises in which fuel-retail is not the primary activity, and also non-fuel-retail PBNs in fuel-retail enterprises.

Data coverage

Table 10 shows the impact, at a national level, of restricting the industrial and geographic scope of our analysis. The data are based on the year to June 2018. Using all GST returns that cover a fuel-retail outlet or enterprise, and information on all PBNs covered by those returns, we find that there is an average of 1,303 PBNs each quarter, covering $14bn of annual GST sales. Because this figure includes non-fuel-retail sales, it overstates national fuel-retail sales by around 70% – official statistics estimates show that national fuel-retail sales in the year to June 2018 amounted to $8.2bn.[29] However, restricting attention to the subset of GST returns that relate solely to fuel-retail outlets in fuel-retail enterprises lead to an understatement of national fuel-retail sales. The first column of Table 10 shows that this subset covers 900 outlets, and only $4.6bn of sales (56% of the official measure of retail sales).

To analyse spatial variation in sales for the Auckland region, the data scope must be further restricted. Using only fuel-retail GST returns that relate to sales from a single region, the number of outlets is reduced to 760, and total fuel-retail sales to $3.7bn (second column of Table 10). For selected analyses, we control for the proximity of outlets to the Auckland region boundary. For those

[28] GST returns are submitted monthly, 2-monthly, or 6-monthly. We impute a monthly GST track for each firm, distributing sales evenly across the months covered by each return. We then aggregate to a consistent (March, June, September, December) quarterly measure of sales.

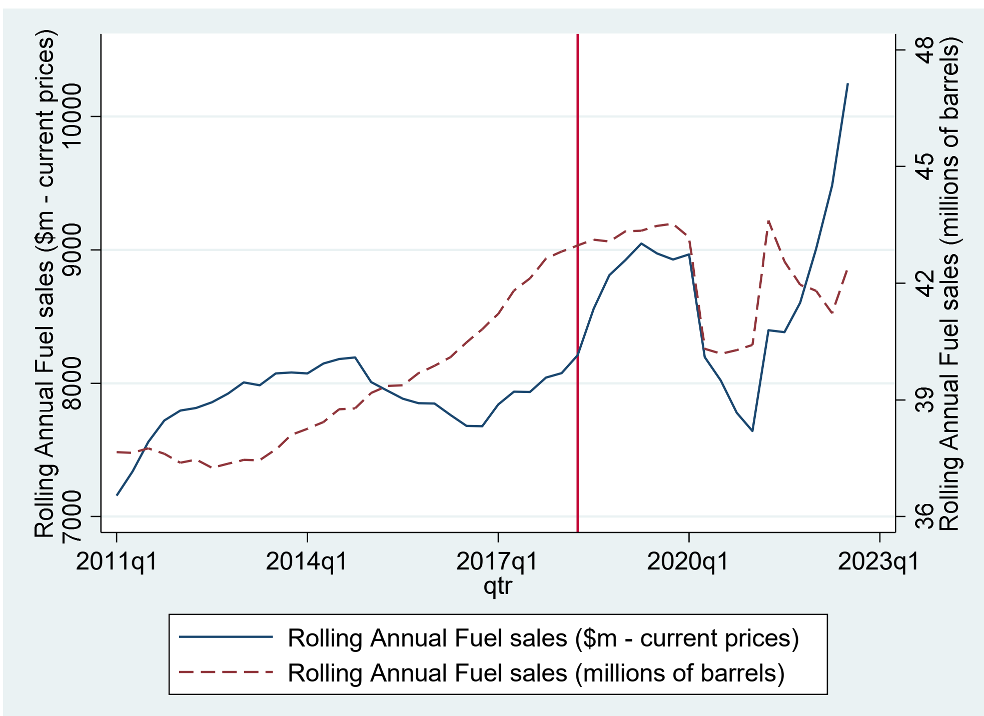
[29] Figure 8 shows Official Statistics estimates of annual fuel-retail sales, based on rolling annual sums of monthly data. In the year to June 2018, national fuel-retail sales amounted to $8.2bn, having risen from $7.8b in the year to January 2016. (https://www.stats.govt.nz/information-releases/retail-trade-survey-september-2022-quarter/, accessed 28 February 2023)

analyses, we restrict attention to GST returns that relate to sales from a single-meshblock. The third column of Table 10 shows that this reduces the coverage to 580 outlets and $2.6bn of fuel sales.

Table 10: National data – outlets and sales (year to June 2018)

	GST return relates entirely to fuel-retail outlets in a fuel-retail enterprise			Other GST returns	Total
	All	Single-region subset	Single-meshblock subset		
Outlets (mean)	900	760	580	403	1303
%	69%	58%	45%	31%	100%
Sales (annual $m)	$4,593	$3,697	$2,602	$9,382	$13,976
%	33%	26%	19%	67%	100%
Annual sales per outlet	$5.1m	$4.9m	$4.5m	$23.3m	$10.7m

Notes: The table summarises all GST returns that cover a fuel-retail outlet (PBN) or a fuel-retail enterprise. Because some of those GST returns include sales from non-fuel-retail PBNs, enterprises, and activities, the total sales overstate national fuel-retail sales. Sales are for 2017q3 – 2018q2.



Source: Statistics New Zealand Retail Sales Survey. (https://www.stats.govt.nz/information-releases/retail-trade-survey-september-2022-quarter/, accessed 28 February 2023

Figure 8: National fuel sales

Table 11 provides a regional breakdown of the number of outlets and fuel sales overall, as well as for subsets of single-region and single meshblock fuel-retail-only GST returns. Based on Auckland's share of total retail sales (37%[30]), we estimate that Auckland's share of fuel-retail sales would have been around $3.0bn in 2018. As shown in the first column of Table 11, estimated Auckland sales in our sample of fuel retailers is just over $1b, or a third of the overall amount – a proportion similar to the national proportion of 33% shown in the first column of Table 10. Single-region GST returns (panel b) cover about $0.9bn, or about 30% of Auckland fuel-retail sales. The number of outlets covered in the region-only subset is 215, compared with the tally of 309 listed in NZTA (2018), or the total of 223 in our sample of fuel-retail outlets. Restricting the sample further to single-meshblock returns reduces coverage to about 19% of sales ($0.6bn) and 46% of outlets. A further caveat relating to the sales data is that GST data contain information on total sales (inclusive of GST and sales tax), and do not distinguish sales of different fuel types or non-fuel sales.

Table 11: Regional data – outlets and sales (year to June 2018)

	Auckland region	Northland region	Waikato region	Other regions	All regions combined
	a) All outlets				
Outlets (mean)	223	48	100	515	887
% (of total)	25%	5%	11%	58%	100%
Sales (annual $m)	$1,073		$422	$3,102*	$4,597
% (of total)	23%		9%	67%*	100%
Annual sales per outlet	$4.8m		$4.2m	$5.5m*	$5.2m
	b) Single-region subsets				
Outlets (mean)	215	39	96	410	760
% (of total)	28%	5%	13%	54%	100%
Sales (annual $m)	$897	$161	$380	$2,259	$3,697
% (of total)	24%	4%	10%	61%	100%
Annual sales per outlet	$4.2m	$4.2m	$3.9m	$5.5m	$4.9m
	c) Single-meshblock subset				
Outlets (mean)	143	31	73	334	580
% (of total)	25%	5%	13%	58%	100%
Sales (annual $m)	$575	$139	$327	$1,562	$2,602
% (of total)	22%	5%	13%	60%	100%
Annual sales per outlet	$4.0m	$4.4m	$4.5m	$4.7m	$4.5m

Notes: * 'Other regions' data for sales include data for the Northland region. Northland Region sales data for 'all outlets' is suppressed in accordance with SNZ rules. The regional shares of sales for multi-region returns (included in panel a) are estimated by allocating sales in proportion to the number of outlets in each region. Numbers in the final column differ from those in Table 10 because the current table shows averages of monthly data, whereas Table 10 shows averages of quarterly data. Numbers may not add due to rounding.

Market dynamics

Table 10 and Table 11 have summarised the coverage of data in the year to June 2018. Table 12 documents changes over time in the number of outlets and in total sales. We focus on changes that occurred in the two years following the introduction of the ARFT – comparing the year to June 2020 with the year to June 2018.

[30] Statistics New Zealand, Retail Trade Survey, June 2018. Available from infoshare.stats.govt.nz.

Changes of 5% to 10% are expected owing to the rounding of the underlying numbers. There are, however, more substantial changes in the number of outlets in the Waikato region (+14%) and in Northland (–17%). In Auckland, the number of outlets increased by 7%, dominated by an increase in the number of outlets associated with firms that operated in more than one meshblock.

Table 12: Regional data – outlets and sales (changes over time)

	Number of outlets			Sales (annual $m)		
	Auckland region	Northland region	Waikato region	Auckland region	Northland region	Waikato region
	(1)	(2)	(3)	(4)	(5)	(6)
	(a) All outlets					
2018	223	48	100	$1,073	*	$422
2019	240	41	109	$1,108	*	$762
2020	240	40	114	$941	*	$760
Change (2018-20)	7%	-17%	14%	-12%		80%
	(b) Single-region subset					
2018	215	39	96	$897	$161	$380
2019	225	35	100	$962	$167	$719
2020	228	35	100	$850	$155	$724
Change (2018-20)	6%	-10%	4%	-5%	-3%	90%
	(c) Single-meshblock subset					
2018	143	31	73	$575	$139	$327
2019	145	29	81	$639	$147	$664
2020	143	29	85	$551	$141	$674
Change (2018-20)	0%	-8%	17%	-4%	2%	106%
	(d) Multi-meshblock subset					
2018	81	17	28	$498	*	$95
2019	95	12	28	$470	*	$98
2020	97	11	29	$390	*	$86
Change (2018-20)	20%	-33%	6%	-22%		-10%

Notes: All numbers are annual averages (for outlets) or sums (for sales) of rounded monthly or quarterly data. Sales by location for multi-meshblock firms are imputed based on the share of each firm's outlets that are in each region.
* Northland region sales data for all outlets and for the multi-meshblock subset are suppressed in accordance with SNZ rules.

Crucially for our estimation approach, there was a very large increase in fuel sales in the Waikato region (+80%), which was well beyond the increase in the number of outlets. This implies that average sales per outlet in Waikato increased more than average sales per outlet in Auckland. The difference is clearly evident for single-region and single-meshblock firms, which are the subsets on which our estimation is based.[31] The slower relative growth in average sales in Auckland is consistent with a negative demand elasticity in response to the relative price increase resulting from the ARFT,

[31] The region-specific sales amounts for multi-meshblock firms should be interpreted with caution as they are imputed. Each firm's sales are allocated to outlets on the assumption that all of its outlets are equally sized. Regional variation in growth rates will be understated.

but suggests that some of the response to higher fuel prices in Auckland was to shift fuel demand to Waikato rather than just to reduce the quantity of fuel demanded.

5.3 Analytical approach

To estimate the price elasticity of fuel-retail sales, we use a difference-in-difference (DiD) specification (equation (7a)). The estimation sample is restricted to single-region GST returns relating solely to fuel-retail outlets that are part of fuel-retail enterprises, and includes only Northland, Auckland, and Waikato outlets. GST sales are measured net of the ARFT.[32] The main parameter of interest in equation (7a) is γ, which captures the proportional change in fuel-retail sales in Auckland following the introduction of the ARFT, net of the change that occurred in other regions. The specification also includes an outlet fixed effect, to absorb outlet-specific differences in sales volumes.[33] In practice, we allow for two distinct post-ARFT periods – pre-Covid (2018q3 – 2020q1) and later (2020q2 – 2021q4).

We estimate a modified version of equation (7a) in which the term $(\gamma * D_{Akld} * D_{Post})$ is replaced by $(\tilde{\gamma} * ARFT\_rate_t * D_{Post})$ (see equation (7b). With this modification, $\tilde{\gamma}$ provides a direct estimate of the price elasticity of demand from fuel. The ARFT-rate is calculated as $\ln\left(p_t/(p_t - \$0.115)\right)$, using the composite price index for Auckland. The ARFT-rate is around 6% to 8%, implying that $\tilde{\gamma}$ will be around 15 times as large as the raw treatment effect γ, reflecting the fact that the estimated impact of the ARFT on sales is a response to a relatively small proportional change in price.

$$\ln Sales_{it} = \alpha_i + \beta_{Akld} + \beta_{Post} + \gamma * D_{Akld} * D_{Post} + \varepsilon_{it} \quad (7a)$$

$$\ln Sales_{it} = \alpha_i + \beta_{Akld} + \beta_{Post} + \tilde{\gamma} * ARFT\_rate_t * D_{Post} + \varepsilon_{it} \quad (7b)$$

The specification in equation (8) provides more detailed time-period controls. It includes quarter-specific intercepts (α_t) and quarter-specific elasticity estimates of the effect of the ARFT on fuel sales in Auckland (γ_t). The quarter immediately prior to the introduction of the ARFT is set as the reference period $\left(\gamma_{2018q} \ = 0\right)$.

$$\ln Sales_{it} = \alpha_i + \alpha_t + \beta_{Akld} + \widetilde{\gamma_t} * ARFT\_rate_t + e_{it} \quad (8)$$

The DiD approach is robust to factors that change over time, such as changes in technology (e.g. growth in use of electric and/or hybrid vehicles) or preferences (e.g. preferences for size or type of vehicle, etc), if such changes are common across the boundary. That is, to cause bias in the DiD estimates, any changes would have to occur differently within, compared to outside, the Auckland boundary. This would be a threat to the so-called common trends assumption in using the DiD approach. As the time frame for the study is relatively short (four years), any such changes would be relatively difficult to identify. Our ability to test the common trends assumption is also limited as we only observed regional prices in the single quarter before the tax became effective. Perhaps the larger threat in the current context is around possibly differential effects of the Covid-19 pandemic in

[32] The ARFT adjustment to sales is $\ln(Sales * (p - \$0.115)/p)$, where *p* is the composite price index for Auckland (see notes to Table 9).

[33] When outlet fixed effects are included, the area-specific intercept (β_{Akld}) is omitted due to collinearity.

versus outside Auckland. For this reason, as discussed above, we consider two distinct post-ARFT effects, corresponding to the pre- versus post-Covid periods.

5.4 Event-study results

This section provides estimates of the price elasticity of fuel-retail sales. We estimate the proportional change in sales around the introduction of the ARFT, comparing the change for Auckland retailers with the change for retailers in neighbouring regions. The estimated difference in sales growth between Auckland and other regions is then related to the proportional change in fuel price to provide an estimated price elasticity of demand.

5.4.1 Baseline results

Table 13[34] reports estimates of γ from equation (7a), using data on GST returns from single-region operators in Northland, Auckland and Waikato. The first column presents estimates of treatment effects for a version of equation (8) that does not include firm fixed effects $(\alpha_i = \alpha)$. The main coefficients of interest are the two coefficients labelled as 'Treatment'. They show that between 2018q3 and 2020q1, average fuel sales by Auckland outlets were around 20% lower than they would have been in the absence of the ARFT, although the estimate is not significantly different from zero. For the later (2020q2-2021q4) period, sales were around 30% lower.[35]

Table 13: Treatment effect estimates: Auckland boundary (Equation (7a))

			Balanced sample		
	Level regression	Fixed effects	Fixed effects	Northern boundary fixed effects	Southern boundary fixed effects
	(1)	(2)	(3)	(4)	(5)
Auckland	0.0126	-1.178***	n/a	n/a	n/a
	(0.0675)	(0.245)			
2018q3 – 2020q1	0.311***	-0.180***	-0.00311	0.100*	-0.0498
	(0.0874)	(0.0401)	(0.0248)	(0.0426)	(0.0315)
2020q2 – 2021q4	0.357***	-0.253***	-0.120***	0.0780	-0.211***
	(0.0868)	(0.0418)	(0.0248)	(0.0426)	(0.0315)
Treatment$_{2018\text{-}2020}$	**-0.201**	**0.0744**	**-0.111****	**-0.214*****	**-0.0646**
	(0.115)	**(0.0530)**	**(0.0343)**	**(0.0484)**	**(0.0402)**
Treatment$_{2020\text{-}2021}$	**-0.359****	**-0.0636**	**-0.179*****	**-0.378*****	**-0.0883***
	(0.115)	**(0.0556)**	**(0.0343)**	**(0.0484)**	**(0.0402)**
N observations	7,380	7,380	3,696	2,463	3,135
N distinct firms	408	408	132	90	111
R-sq	0.005	0.023	0.058	0.076	0.065
Adj. R-sq	0.004	-0.035	0.021	0.039	0.028

Notes: Observation is a GST Sales return. Sample includes GST returns from single-region operators in Northland, Auckland and Waikato. The balanced subsample is for returns that are available for each of the 28 quarters in the sample period (2015q1 – 2021q4). Observation counts and firm counts have been rounded.

[34] We have run a set of regressions that also include ln(number of outlets in the regional council) as an additional covariate. The estimates are different, but the pattern of results is generally similar to what is currently included in Tables 13-14.

[35] $e^{-0.201}-1 = 18\%$; $e^{-0.359}-1 = 30\%$

In the second column of Table 13, we report estimates that include firm fixed effects, to control for the changing composition of firms and outlets. Controlling for firm fixed effects in the second column greatly reduces the estimated impact, and yields statistically insignificant estimates. It appears that the estimates in the first column reflect the presence of high-sales-volume outlets outside Auckland after the introduction of the ARFT. As shown in Table 12, the number of outlets increased in both Auckland and Waikato, with the average sales volumes in Waikato increasing particularly strongly.

In columns 3-5 of Table 13, we report estimates based on a sample of firms that operated continuously throughout the 2015q1 – 2021q4 period ('balanced' sample).[36] The pooled estimates in column 3 show significant negative treatment effects in both the short term (2018–2020: –0.11) and the medium term (2020–2021: –0.18). The effect is stronger across the Northern (Auckland-Northland) boundary than it is across the Southern (Auckland-Waikato) boundary.

Table 14: Elasticity estimates: Auckland boundary (Equation (7b))

			Balanced sample		
	Level regression	Fixed effects	Fixed effects	Northern boundary fixed effects	Southern boundary fixed effects
	(1)	(2)	(3)	(4)	(5)
Auckland	0.0208	-1.170***	n/a	n/a	n/a
	(0.0671)	(0.245)			
2018q3 – 2020q1	0.315***	-0.174***	-0.00149	0.102*	-0.0470
	(0.0873)	(0.0400)	(0.0247)	(0.0425)	(0.0314)
2020q2 – 2021q4	0.372***	-0.240***	-0.117***	0.0776	-0.205***
	(0.0860)	(0.0413)	(0.0246)	(0.0417)	(0.0311)
Elasticity$_{2018\text{-}2020}$	**-3.283**	**1.020**	**-1.805*** **	**-3.409*** **	**-1.093**
	(1.822)	**(0.835)**	**(0.542)**	**(0.762)**	**(0.634)**
Elasticity$_{2020\text{-}2021}$	**-5.658*** **	**-1.274**	**-2.705*** **	**-5.539*** **	**-1.438***
	(1.666)	**(0.798)**	**(0.498)**	**(0.690)**	**(0.581)**
N observations	7,380	7,380	3,696	2,463	3,135
R-sq	0.005	0.023	0.058	0.077	0.065
Adj. R-sq	0.004	-0.035	0.022	0.041	0.029

Notes: Observation is a GST Sales return. Sample includes GST returns from single-region operators in Northland, Auckland and Waikato. The balanced subsample is for returns that are available for each of the 28 quarters in the sample period (2015q1 – 2021q4).

The negative estimated treatment effects are related to a price change of 6% to 8%. The estimates in Table 14 show the implied price elasticities, using equation (7b). The elasticity estimates are large, with statistically significant estimates ranging from –1.4 to –5.7. Figure 9 shows the quarterly pattern of treatment effects for the balanced fixed effects sample. Elasticities are shown for 2018q3 to 2021q4. While negative estimated elasticities are evident for the ARFT period, the confidence intervals around the estimates are large, and are generally not significantly different from zero.

[36] The Auckland coefficient is identified solely from firms that operate in Auckland in some periods and in either Waikato or Northland in other periods.

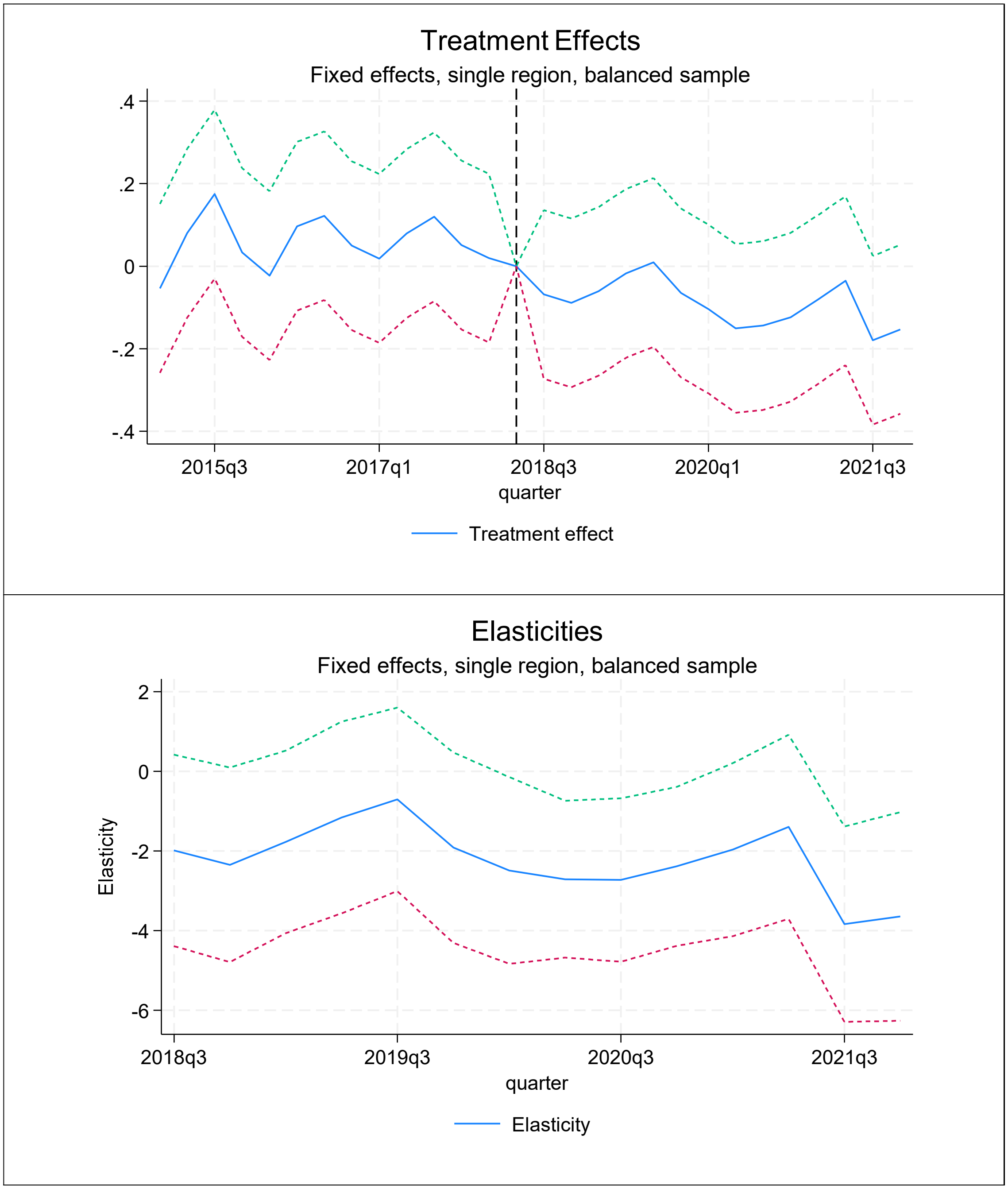


Figure 9: Quarterly treatment effects and elasticities (single-region firms)

5.4.2 Robustness checks

As a robustness check of the large estimated elasticities reported in Table 14, we repeat the analysis, controlling for proximity to the Auckland regional boundary. Table 15 repeats the analysis contained in Table 14, but for a sample of single-meshblock firms. This sample restriction is necessary so that the distance of each outlet from the boundary can be calculated. We associate each Auckland outlet with its nearest boundary, so that outlets close to the southern boundary do not contribute to estimated elasticities for the northern boundary (and vice versa). For the analysis of single-meshblock firms, we include an additional covariate, being the number of outlets within a 10km radius, to control for local competition among suppliers. The results in the first two columns of Table 15 are similar to the corresponding Table 14 results (columns 4 and 5) based on single-region firms, with large negative estimated price elasticities for the balanced subsample – particularly across the Northern boundary.

Table 15: Elasticity estimates: Single meshblock outlets (fixed-effect estimates)

	Balanced		Balanced More than 30km from boundary		Balanced 30km-60km from boundary	
	Northern boundary	Southern boundary	Northern boundary	Southern boundary	Northern boundary	Southern boundary
	(1)	(2)	(3)	(4)	(5)	(6)
2018q3 – 2020q1	0.0998*	-0.0526	0.0634	-0.0776*	0.0401	0.105
	(0.0429)	(0.0331)	(0.0484)	(0.0313)	(0.0455)	(0.0832)
2020q2 – 2021q4	0.0780	-0.202***	0.0963*	-0.246***	0.0905*	0.0577
	(0.0424)	(0.0332)	(0.0478)	(0.0316)	(0.0455)	(0.0806)
Elasticity$_{2018\text{-}2020}$	**-3.230*** **	**-0.871**	**-2.877** **	**0.694**	**-0.837**	**-2.832***
	(0.809)	**(0.681)**	**(0.890)**	**(0.664)**	**(1.019)**	**(1.376)**
Elasticity$_{2020\text{-}2021}$	**-5.253*** **	**-1.206**	**-5.737*** **	**0.893**	**-7.343*** **	**-3.591** **
	(0.750)	**(0.620)**	**(0.827)**	**(0.607)**	**(0.951)**	**(1.207)**
N observations	2,268	2,856	2,100	2,379	393	1,146
N distinct firms	81	102	75	84	12	39
R-sq	0.072	0.060	0.072	0.054	0.220	0.049
Adj. R-sq	0.034	0.022	0.035	0.016	0.034	0.007

Notes: Regressions also include controls for the number of outlets within a 10km radius of each meshblock each year. Boundary-specific estimates include only those Auckland outlets that are closer to the focal boundary than to the opposite boundary. Counts are rounded.

In columns 3 and 4 of Table 15, we exclude outlets that are within 30km of each boundary, while still assigning Auckland outlets to their nearest boundary.[37] Auckland outlets are thus between 30km and 60km from the boundary, whereas outlets in neighbouring regions could be further than 60km from the boundary.

We expect estimates based on these restricted samples to be less influenced by cross-boundary fuel purchases, and therefore to show smaller (closer to zero) elasticities. For the Northern boundary, the estimates from the restricted sample are similar to the unrestricted estimates in Table 14 (column 4). For the Southern boundary, the estimates remain insignificant, with (perversely) positive point estimates.

In the final two columns of Table 15, we further restrict the sample by removing outlets in Northland and Waikato if they are more than 60km from the Auckland regional boundary. This removes the

[37] The impact of the 30km restriction can be seen in Figure 7, being the area covered by the circle and ellipse. Assigning Auckland outlets to their nearest border has a more substantial impact – particularly for the Northern border sample, as it excludes many Auckland outlets that are closest to the Southern border (see Figure 6).

influence of sales changes in more distant locations, including those in Whangarei, Tauranga, Hamilton, and Taupo. This restriction considerably reduces the number of observations and the number of distinct firms, but also isolates a subset of non-Auckland outlets that are likely to represent a more credible counterfactual for Auckland outlets. The estimates in columns 5 and 6 show negative own-price elasticities across the Northern boundary of between –0.8 and –7.3, and across the Southern boundary of between –2.8 and –3.6. The confidence intervals are, however, large, reflecting heterogeneous patterns among the relatively small samples.

5.4.3 Discussion

The estimates of the price elasticity of fuel demand that are reported based on the effects of the ARFT are large. The point estimates[38] are centred around –2, implying that the 6% price increase resulting from the introduction of the ARFT led to more than a 10% relative reduction in retail fuel sales in Auckland. Our estimates lack precision, so we are not confident of the exact magnitude of spatial price elasticities of demand. However, the estimates are significantly different from zero, with confidence intervals that span from –3.7 to –0.7, indicating a relatively strong own-price elasticity of demand for fuel.

The imprecision may in part reflect the fact that the data we use are not ideal for the analysis of spatial demand. Due to imperfect identification of fuel-retail outlets, and limitations of linking GST sales to specific outlets, our estimates are based on sales in a non-random subset of outlets. We restrict attention to GST returns that relate to fuel-retail outlets that are part of fuel-retail firms and that operate in only one region, or in only one meshblock. There were, however, changes in the number of outlets and the volume of sales accounted for by other fuel-retail firms in Auckland, Waikato, and Northland, which we control for imperfectly.

An estimated price elasticity of fuel demand of –2 is a much stronger response than is found in sections 3.3 and 4.3, or in the international literature, based on time-series or household-level analysis (Graham & Glaister, 2002; Miller & Alberini, 2016). It is, however, in line with international studies of cross-border differences in fuel prices. Leal et al (2009) and Iraizoz & Labeaga (2022) both estimate a price elasticity of around –2.5 estimated from cross-border tax differentials. Banfi et al (2005) report that fuel demand increases by 17% in response to a 10% rise in price in a neighbouring region, implying an elasticity greater than –1.7 if quantity demanded declined in the region with the price increase. The greater responsiveness of demand to price variation is explained by the ease of substitution that is possible with cross-border purchases. Although cross-border purchasing is not feasible for all consumers, there is a sufficiently large volume of sales that can be redirected. In the case of the ARFT, the presence of fuel retailers on State Highway 1 close to the Auckland region borders make it relatively easy for high-volume fuel consumers to purchase in Waikato or in Northland. The rise in outlets and sales in Waikato (as reported in Table 12) is consistent with such a redirection of retail demand, although it is not possible to identify the extent to which this redirection represents additional cross-border trips to purchase fuel, or is due to a different choice of fuelling stops for existing inter-regional journeys.

The ability of consumers to redirect their fuel demand in response to the cross-border price differentials has implications for the overall impact of the ARFT, or of similar spatially-defined fuel price policies. First, the amount of tax revenue will be reduced by the shifting of retail sales to neighbouring (lower-tax) regions. Second, the impact of a local fuel sales tax on reducing VKT, or

[38] Column 3, Table 14: balanced sample of single-region firms, fixed-effects estimates.

on reducing emissions will be offset by cross-border trips generated by the avoidance of the local tax. Finally, the findings reinforce the general insight that the strength of response to price changes depends on the ease of substitution between different commodities. The availability of alternatives to petroleum-based fuels and vehicles, like the local availability of different priced fuels, is likely to raise the price elasticity of retail fuel demand.

6 Concluding discussion

This study uses three distinct approaches to estimating transport elasticities for New Zealand: cross section, time series, and event studies. Although, in principle, the approaches are estimating comparable elasticities, there are important differences that may affect their comparability. In this section, we summarise the key findings, and discuss the comparability between the approaches and their strengths and weaknesses.

6.1 Key findings

Using cross-sectional household-level data from 2005–2019, we estimate that price elasticity of petrol demand is –0.66 based on time-series regional price variation, and about –0.4 based on national prices.[39] Based on time-series regional prices, the price elasticity of petrol demand ranges from –0.78 for the lowest expenditure quintile to –0.43 for the highest expenditure quintile, indicating that petrol demand is price-inelastic, and more so for richer households. These estimates are in the range of around –0.2 to –1.1 estimated by previous international studies using household- or individual-level survey data. The estimated median expenditure elasticity for petrol is 0.85, suggesting that petrol is a necessity good. By contrast, Other transport is estimated to be a luxury and the demand for it is price-elastic.

Based on time-series data, we find that for the period 1978–2019, the short-run price elasticity of aggregate petrol consumption estimated from 4-quarter distributed lag models tends to be small (-0.11), while the long-run elasticity is about –0.19. Using VEC models, we observe similar effects over 1-2 years, but larger longer-run effects (over –0.3) after 4-5 years during which time other factors such as technology and incomes may also change. These results indicate that at the aggregate level, petrol demand is very price-inelastic, and more so in the short run than in the longer run. These estimates are well within the range of around –0.03 to –0.3 estimated by previous international studies using aggregate data. We find that elasticity with respect to GDP per capita is about 0.2, indicating that petrol is a necessity good.

Thus, consistent with the international literature, we find that petrol demand is more price-inelastic when estimated using time-series data than when using household-level data. The finding that long-run price elasticity is almost twice the short-run elasticity is in line with the literature.

The event-study approach, which examines changes in fuel-retail sales volumes around the time that the ARFT was introduced (1 July 2018), estimates price elasticity of fuel demand around –2. This result implies that the spatial demand for fuel is very elastic: the 6% price increase resulting from the introduction of the ARFT led to more than a 10% relative reduction in retail fuel sales in Auckland, relative to neighbouring regions. It is, however, in line with international studies of cross-border tax differentials, which estimate price elasticities of local fuel demand of around –2.5.

[39] The estimated elasticity based on regional prices is lower in magnitude (–0.40) when air transport is excluded. The estimated price elasticity of demand using time-series national prices varies from –0.33 to –0.46 depending on the number of expenditure categories used (see Table 4).

6.2 Strengths and limitations

There are some potentially important differences associated with the three approaches that may drive the differences in estimates. First, as the HES is a household-level survey, the resulting analysis necessarily focuses on fuel responses by private households; in contrast, the time-series analysis focuses on the aggregate economy fuel responses (i.e. including commercial sectors). In addition, the time periods of analysis differ between the HES (2006/7–2018/19) and aggregate time series (1978–2019). We do not have priors as to how these differences will affect the estimates but, for example, if households are more responsive to fuel price changes than non-households, the HES elasticity estimates are expected to be larger than the time-series estimates.

Second, both the HES and time-series analyses use analogous, aggregate time-series, price variation. However, the aggregate time-series analysis is concerned with removing non-stationarity from the expenditure and price trends, while the HES cross-sectional analysis exploits regional variation in fuel prices and controls for prices of other goods and broad household characteristics. Figure 1 indicates a steady fall in petrol expenditure over the past 20 years and suggests a negative correlation with fuel prices. On the one hand, to the extent these reflect secular increasing trends in fuel prices over time and decreasing trends in fuel consumption (e.g. associated with greater fuel efficiency and growth in electric and hybrid vehicle use), this analytical difference is likely to result in the HES elasticity estimates being upwardly biased in magnitude relative to the time-series estimates. On the other hand, as Levin et al. (2017) demonstrate, the time-series analysis does not capture macroeconomic fluctuations that may influence both fuel demand and fuel prices, resulting in lower price elasticities.

Third, the event-study estimates are expected to capture behavioural responses of *where* (i.e. which side of the boundary) to buy fuel in response to the ARFT, as well as any (pure) consumption response. For this reason, these elasticity estimates are of greater value for understanding the spatial expenditure responses to fuel price differences, and are not directly comparable to the aggregate time-series and cross-sectional HES estimates. The fact that they are relatively higher than the cross-sectional and time-series estimates suggests that consumers expenditure patterns are substantially more responsive to local price variation than implied by the own-price elasticity estimates based on national variation. Also, related to this point, that the HES estimated own-price elasticity is larger based on regional than aggregate prices is consistent with the former identified response including a spatial expenditure component as well as any consumption response. This highlights the distinction between ‘expenditure’ and ‘consumption’, as well as the shortcoming of estimating elasticities using national-level price variation.

Despite these issues, there is some broad consistency between the aggregate time-series and the HES-based cross-sectional estimates of the price elasticity of petrol demand. We think a reasonable range is from about –0.2 to –0.4, depending on the time frame of response and possible upwards bias associated with negatively correlated secular trends in prices and demand. Allowing for some likely secular trends in prices and demand, the higher HES estimates are expected to be somewhat overstated, while the price elasticity of demand estimates based on the time-series analysis range from a response of about –0.2 over 1-2 years to somewhat larger (perhaps –0.3) allowing for other changes over the longer term (4-5 years).

Given the limitations of the different data sets, the different approaches allow us to examine price elasticity of transport goods from various perspectives. The different fuel cross-price elasticities estimated by this study represent a range of possible consumer responses when modelling the impact of price changes. Indeed, these estimates represent different elasticates and provide answers to different questions. Specifically, the time-series estimates show aggregate responses in total petrol consumption, ignoring heterogeneity of demand and macroeconomic factors not captured by the time trend. The household-level estimates provide insights into households' responses given changes in prices of petrol and other goods, and their circumstances and preferences. The ARFT estimates are useful for predicting responses in a local area in the presence of price differentials in nearby markets. From the aggregate perspective, petrol demand is very price-inelastic due to the lack of a close substitute, yet in the local market near the Auckland region boundary, petrol demand is very price-elastic due to the availability of a perfect substitute in the vicinity.

Our estimates are subject to several limitations. First, zero expenditures are widespread in the HES data (partly due to the relatively short diary-keeping period), while the CPI price data contain little geographic variation, making them not particularly suited for the demand system modelling used in the household-level analysis. Furthermore, due to software limitations, standard errors have not been calculated for elasticity estimates from the household-level analysis. Second, VKT elasticity cannot be estimated as the available VKT data cover only a short time series. Third, the event-study estimates lack precision because the data we use are not ideal for the analysis of spatial demand. These data do not distinguish sales of different fuel types or non-fuel sales. Due to imperfect identification of fuel-retail outlets, and limitations of linking GST sales to specific outlets, our estimates are based on sales in a non-random subset of outlets.

6.3 Next steps

Given the limitations outlined above, this study can be extended in several ways. First, the household-level analysis should be updated to allow for standard errors to be calculated when Stata 18 is available in Statistics New Zealand's data lab. Second, the time-series approach can be used to estimate VKT elasticity when a longer time series of VKT data or more geographically disaggregated data on fuel prices are available. Third, when available electronic card transactions data can be used in place of GST data as a robustness check on the event-study approach.

References

Banfi, S., Filippini, M., & Hunt, L. C. (2005). Fuel tourism in border regions: The case of Switzerland. *Energy Economics*, *27*(5), 689–707.

Banks, J. W., Blundell, R. W., & Lewbel, A. (1997). *Quadratic Engel Curves and Consumer Demand*. *79*(4), 527–539.

Bergantino, A. S. (1997). Estimating Engel curves for transport expenditures: Evidence from UK household budget data. *International Journal of Transport Economics/Rivista Internazionale Di Economia Dei Trasporti*, *24*(2), 279–305.

Bergantino, A. S., Capurso, M., & Toner, J. (2018). *Households' expenditure elasticities for transport products and services: A geo-demographic approach* [Working Paper].

Berry, S. T., & Haile, P. A. (2021). Foundations of demand estimation. In *Handbook of Industrial Organization* (Vol. 4, pp. 1–62). Elsevier.

Bushnell, J. B., Muehlegger, E., & Rapson, D. S. (2022). *Energy Prices and Electric Vehicle Adoption (No. W29842)* [Working Paper]. https://www.nber.org/papers/w29842

Commerce Commission of New Zealand. (2019). *Market study into the retail fuel sector: Final report*. Commerce Commission of New Zealand. https://comcom.govt.nz/__data/assets/pdf_file/0028/193915/Retail-fuel-market-study-Final-report-5-December-2019.PDF

Deaton, A., & Muellbauer, J. (1980). An Almost Ideal Demand System. *American Economic Review*, *70*(3), 312–326.

Feng, Y., Fullerton, D., & Gan, L. (2013). Vehicle choices, miles driven, and pollution policies. *Journal of Regulatory Economics*, *44*(1), 4–29. https://doi.org/10.1007/s11149-013-9221-z

Goldberg, P. K. (1998). The effects of the corporate average fuel efficiency standards in the US. *The Journal of Industrial Economics*, *46*(1), 1–33.

Graham, D. J., & Glaister, S. (2002). The demand for automobile fuel: A survey of elasticities. *Journal of Transport Economics and Policy*, 1–25.

Greene, D. L. (1992). Vehicle Use and Fuel Economy: How Big is the "Rebound" Effect? *The Energy Journal*, *13*(1). https://doi.org/10.5547/ISSN0195-6574-EJ-Vol13-No1-7

Hall, V., & McDermott, J. (2007). *A Quarterly Post-World War II Real GDP Series for New Zealand* (Motu Working Paper 07–13). Motu Economic and Public Policy Research.

Holt, M. T., & Goodwin, B. K. (2009). Chapter 2 The Almost Ideal and Translog Demand Systems. In D. J. Slottje (Ed.), *Quantifying Consumer Preferences* (Vol. 288, pp. 37–59). Emerald Group Publishing Limited. https://doi.org/10.1108/S0573-8555(2009)0000288005

Hughes, J., Knittel, C. R., & Sperling, D. (2008). Evidence of a Shift in the Short-Run Price Elasticity of Gasoline Demand. *The Energy Journal*, *29*(1). https://doi.org/10.5547/ISSN0195-6574-EJ-Vol29-No1-9

Iraizoz, A., & Labeaga, J. M. (2022). *Incidence and Avoidance Effects of Spatial Fuel Tax Differentials: Evidence using Regional Tax Variation in Spain*. https://shs.hal.science/halshs-03789430/document

Kayser, H. A. (2000). Gasoline demand and car choice: Estimating gasoline demand using household information. *Energy Economics*, *22*(3), 331–348. https://doi.org/10.1016/S0140-9883(99)00043-2

Kennedy, D., & Wallis, I. (2007). *Impacts of fuel price changes on New Zealand transport* (331; Land Transport New Zealand Research Report, p. 138). Land Transport New Zealand. https://www.nzta.govt.nz/assets/resources/research/reports/331/docs/331.pdf

Khaled, M., & Lattimore, R. (2006). The changing demand for apparel in New Zealand and import protection. *Journal of Asian Economics*, *17*(3), 494–508. https://doi.org/10.1016/j.asieco.2006.02.008

Khaled, M., & Lattimore, R. (2008). New Zealand's 'love affair' with houses and cars. *New Zealand Economic Papers*, *42*(1), 127–148. https://doi.org/10.1080/00779950809544416

Kim, H.-G. (2007). *An analysis of income distribution effects of a gasoline tax: Evidence from the U.S. micro-level data* [Ph. D., University of Missouri--Columbia]. https://doi.org/10.32469/10355/4688

Knittel, C. R. (2012). Reducing Petroleum Consumption from Transportation. *Journal of Economic Perspectives*, *26*(1), 93–118.

Knittel, C. R., & Sandler, R. (2011). *Cleaning the Bathwater with the Baby: The Health Co-Benefits of Carbon Pricing in Transportation* (Working Paper 17390; NBER Working Paper Series). National Bureau of Economic Research. https://doi.org/10.3386/w17390

Knittel, C. R., & Tanaka, S. (2021). Fuel economy and the price of gasoline: Evidence from fueling-level micro data. *Journal of Public Economics*, *202*, 104496. https://doi.org/10.1016/j.jpubeco.2021.104496

Leal, A., López-Laborda, J., & Rodrigo, F. (2009). Prices, taxes and automotive fuel cross-border shopping. *Energy Economics*, *31*(2), 225–234.

Levin, L., Lewis, M. S., & Wolak, F. A. (2017). High Frequency Evidence on the Demand for Gasoline. *American Economic Journal: Economic Policy*, *9*(3), 314–347. https://doi.org/10.1257/pol.20140093

Marilena, F., & Francesco, C. (2017). Beyond the mean: Estimating consumer demand systems in the tails. *Agricultural Economics (Zemědělská Ekonomika)*, *63*(No. 10), 449–460. https://doi.org/10.17221/70/2016-AGRICECON

Mhurchu, C. N., Eyles, H., Schilling, C., Yang, Q., Kaye-Blake, W., Genç, M., & Blakely, T. (2013). Food Prices and Consumer Demand: Differences across Income Levels and Ethnic Groups. *PLOS ONE*, *8*(10), e75934. https://doi.org/10.1371/journal.pone.0075934

Michelini, C. (1999). New Zealand household consumption patterns 1983–1992: An application of the almost-ideal-demand-system. *New Zealand Economic Papers*, *33*(2), 15–26. https://doi.org/10.1080/00779959909544305

Miller, M., & Alberini, A. (2016). Sensitivity of price elasticity of demand to aggregation, unobserved heterogeneity, price trends, and price endogeneity: Evidence from US Data. *Energy Policy*, *97*, 235–249.

Ministry for the Environment. (2022a). *New Zealand's Greenhouse Gas Inventory 1990–2020*. https://environment.govt.nz/publications/new-zealands-greenhouse-gas-inventory-1990-2020/

Ministry for the Environment. (2022b). *Towards a productive, sustainable and inclusive economy: Aotearoa New Zealand's first emissions reduction plan*. https://environment.govt.nz/publications/aotearoa-new-zealands-first-emissions-reduction-plan/

Ministry of Transport. (2022). *The Distributional Impacts of Transport-related Carbon Policy* [Transport Evidence Base report]. Ministry of Transport.

Nicol, C. J. (2003). Elasticities of demand for gasoline in Canada and the United States. *Energy Economics*, *25*(2), 201–214. https://doi.org/10.1016/S0140-9883(03)00002-1

NZTA. (2018). *Auckland region service stations*. https://www.nzta.govt.nz/vehicles/regional-fuel-tax/

Park, S. Y., & Zhao, G. (2010). An estimation of U.S. gasoline demand: A smooth time-varying cointegration approach. *Energy Economics*, *32*(1), 110–120. https://doi.org/10.1016/j.eneco.2009.10.002

Pickrell, D., & Schimek, P. (1999). Growth in motor vehicle ownership and use: Evidence from the Nationwide Personal Transportation Survey. *Journal of Transportation and Statistics*, *2*(1).

Poi, B. P. (2012). Easy demand-system estimation with quaids. *The Stata Journal*, *12*(3), 433–446.

Puller, S. L., & Greening, L. A. (1999). Household adjustment to gasoline price change: An analysis using 9 years of US survey data. *Energy Economics*, *21*(1), 37–52. https://doi.org/10.1016/S0140-9883(98)00006-1

Savin, N. E., & White, K. J. (1977). The Durbin-Watson test for serial correlation with extreme sample sizes or many regressors. *Econometrica: Journal of the Econometric Society*, 1989–1996.

Schmalensee, R., & Stoker, T. (1999). Household gasoline demand in the United States. *Econometrica*, *67*(3), 645–662.

Sheng, M., & Sharp, B. (2019). Aggregate road passenger travel demand in New Zealand: A seemingly unrelated regression approach. *Transportation Research Part A: Policy and Practice*, *124*, 55–68. https://doi.org/10.1016/j.tra.2019.03.005

Simic, A., & Bartels, R. (2013). *Drivers of demand for transport*. 52.

Small, K. A., & Van Dender, K. (2007). Fuel Efficiency and Motor Vehicle Travel: The Declining Rebound Effect. *The Energy Journal*, *28*(1). https://doi.org/10.5547/ISSN0195-6574-EJ-Vol28-No1-2

Statistics New Zealand. (2018). *Household transport cost indexes methodological document*. https://www.aa.co.nz/assets/about/Research-Foundation/Transport-Costs/Methodological-document.pdf

Statistics New Zealand. (2020). *Household expenditure statistics: Year ended June 2019*. https://www.stats.govt.nz/information-releases/household-expenditure-statistics-year-ended-june-2019/

Stephenson, J. (2021). *All you can heat? Welfare implications of high fixed charge tariffs for electricity* [Thesis, Master of Science].

Thomas, A. (2019). *Who Would Win from a Multi-rate GST in New Zealand: Evidence from a QUAIDS Model* [Victoria University of Wellington]. http://hdl.handle.net/10063/8127

Torshizian, E., & Isack, E. (2020). *Estimating demand for public transport: Final report to Auckland Transport by NZIER and Principal Economics*.

Torshizian, E., & Meade, R. (2020). *Estimating demand for competition analysis: A statistical exploration, and some possible applications.* https://www.think-asia.org/bitstream/handle/11540/11565/estimating-demand-for-competition-analysis.pdf?sequence=1

Wallis, I. (2004). *Review of passenger transport demand elasticities* (248; Transfund New Zealand Research Report). Transfund New Zealand. https://www.nzta.govt.nz/assets/resources/research/reports/248/248-Review-of-passenger-transport-demand-elasticities.pdf

Wardman, M. (2014). Price elasticities of surface travel demand a meta-analysis of UK evidence. *Journal of Transport Economics and Policy (JTEP)*, *48*(3), 367–384.

Wardman, M. (2022). Meta-analysis of price elasticities of travel demand in Great Britain: Update and extension. *Transportation Research Part A: Policy and Practice*, *158*, 1–18. https://doi.org/10.1016/j.tra.2022.01.020

West, S. E. (2004). Distributional effects of alternative vehicle pollution control policies. *Journal of Public Economics*, *88*(3–4), 735–757. https://doi.org/10.1016/S0047-2727(02)00186-X

Appendix

A1. Transportation expenditure classification

This classification system is based on one developed by Statistics New Zealand for their transportation cost index as delineated in Statistics New Zealand (2018).

- Vehicle purchasing costs
  - Purchase of second-hand motor cars
  - Purchase of new motor cars
- Fuels and lubricants
  - Petrol
  - Diesel
  - Oil, grease, lubricants for vehicles
- Registration, WOF, RUC, parking, licence fees etc
  - Vehicle relicensing fees
  - Parking fees
  - Warrant-of-fitness fees
  - Road user charges
  - Motoring organisation subscriptions
  - Driver licensing fees
  - Driving tuition
- Vehicle parts and maintenance
  - Tyres
  - Vehicle servicing
  - Cambelt repairs
  - Transmission repairs
  - Panelbeating, painting
  - Other electrical parts
  - Automotive batteries
  - Brake repairs
- Vehicle insurance
- Vehicle interest
- Public transport
  - Urban train fares
  - Short distance bus fares
  - Urban ferry fares
- Cycling
  - New bicycles, BMX bikes, mountain bikes
  - Bicycle accessories
  - Contents insurance

A2. CPI classes for the Transport group

New Zealand CPI data can be disaggregated into 11 (level 1) groups, which can then be further disaggregated into 44 sub-groups (level 2) and 109 classes (level 3). The ‘transport’ group in particular consists of 14 classes:

- Purchase of new motor cars
- Purchase of second-hand motor cars
- Purchase of motorcycles
- Purchase of bicycles
- Vehicle parts and accessories
- Petrol
- Other vehicle fuels and lubricants
- Vehicle servicing and repairs
- Other private transport services
- Rail passenger transport
- Road passenger transport
- Domestic air transport
- International air transport
- Sea passenger transport

A3. Appendix tables

Appendix Table 1: HES expenditure categories and corresponding CPI classes

Expenditure category	NZHEC codes	Description	Corresponding price data
	(1)	(2)	(3)
Groceries	01.1 01.2 01.3 01.4	Fruit and vegetables Meat, poultry and fish Grocery food Non-alcoholic beverages	Food price indices for 15 main centres*
Eating out	01.5	Restaurant meals and ready-to-eat food	Food price indices for 15 main centres*
Alcohol & tobacco	02.1 02.2	Alcoholic beverages Cigarettes and tobacco	Regional CPI for 'Alcoholic beverages and tobacco' group
Clothing & footwear	03.1 03.2	Clothing Footwear	Regional CPI for 'Clothing & footwear' group
Housing	04.1 04.2 04.3 04.4	Actual rentals for housing Home ownership Property maintenance Property rates and related services	Regional CPI for 'Housing and household utilities' group
Household energy	04.5	Household energy	Regional CPI for 'Housing and household utilities' group
Household contents	05.1 05.2 05.3 05.4 05.5 05.6	Furniture, furnishings and floor coverings Household textiles Household appliances Glassware, tableware and household utensils Tools and equipment for house and garden Other household supplies and services	Regional CPI for 'Household contents and services' group
Health	06	Medical products, appliances and equipment; Out-patient services; Hospital services	Regional CPI for 'Health' group
Vehicle purchase	07.1	Purchase of vehicles	Regional CPI for 'Transport' group
Petrol	07.2.02	Petrol	Regional CPI for 'Petrol' class
Other private transport	07.2.01 07.2.03 07.2.04 07.2.05	Vehicle parts and accessories Other vehicle fuels and lubricants Vehicle servicing and repairs Other private transport services	Regional CPI for 'Transport' group
Public transport	07.3.01 07.3.02 07.3.05	Rail passenger transport Road passenger transport Sea passenger transport	Regional CPI for 'Transport' group
Air transport	07.3.03 07.4.04	Domestic air transport International air transport	Regional CPI for 'Transport' group
Communication	08	Postal services; Telecommunication equipment; Telecommunication services	Regional CPI for all groups
Recreation & culture	09	Audio-visual and computing equipment; Major recreational and cultural equipment; Other recreational equipment and supplies; Recreational and cultural services; Newspapers, books and stationery; Accommodation services	Regional CPI for 'Recreation & culture' group

Education	10	Early childhood education; Primary and secondary education; Tertiary and other post school education; Other educational fees	Regional CPI for all groups
Insurance	11.4	Life insurance; Dwelling insurance; Contents insurance; Health insurance; Vehicle insurance	Regional CPI for 'Miscellaneous goods and services' group
Personal miscellaneous	11.1 11.3 11.6	Personal care Personal effects Other miscellaneous services	Regional CPI for 'Miscellaneous goods and services' group
Excluded			**Reason for exclusion**
Credit services	11.5	Application fees and service fees for: mortgages, other loans, credit sales, bank accounts, store credit accounts, credit cards, cheques, financial intermediation services	Small, not clear which group to aggregate with
Interest payments	13.1	Interest payments on: mortgages, other loans, credit sales, bank accounts, store credit accounts, credit cards	Not in the CPI
Miscellaneous cash expenses	13.2 13.3 13.4	Contributions to savings Money given to others (excluding donations) Fines	Not in the CPI
Sales, trade-ins and refunds	14	Sales; Trade-ins; Cash receipts from claims on insurance; Other refunds	Not in the CPI

Notes: More details about CPI data are discussed in section 3.2

*Households that live outside the 15 main centres are allocated the value of the nearest centre.

Appendix Table 2: Mean budget shares by category

	Mean budget share	Proportion of sample not reporting expenditure	Mean budget share (excl. housing and durables)	Proportion of sample not reporting expenditure (aggregated grouping)
	(1)	(2)	(3)	(4)
Groceries	0.136	0.021	0.209	0.015
Eating out	0.048	0.184	0.074	
Alcohol & tobacco	0.028	0.436	0.043	0.442
Clothing & footwear	0.035	0.467	0.053	0.474
Housing	0.226	0.020	*	*
Household energy	0.042	0.029	0.064	0.03
Household contents	0.047	0.124	*	*
Health	0.031	0.349	0.047	0.354
Vehicle purchase	0.054	0.770	*	*
Petrol	0.039	0.314	0.060	0.318
Other private transport	0.026	0.118	0.040	0.08
Public transport	0.009	0.698	0.013	
Air transport	0.028	0.692	0.043	
Recreation & culture	0.107	0.068	0.131#	0.082#
Communication	0.033	0.075	0.051	0.011
Education	0.016	0.733	0.025	
Miscellaneous	0.043	0.144	0.066	
Insurance	0.052	0.108	0.080	

Source: Calculated from Household Economic Survey 2006/07, 2009/10, 2012/12, 2015/16, 2018/19
Notes: *Dropped as housing/durables. #Durable items (within 'Recreation & culture') are excluded.

Appendix Table 3: Descriptive statistics of estimation sample

Number of households	16,224*
Mean household size	2.550 (1.397)#
Share of households with*	
Children (aged 0-14)	0.301
People aged 65+	0.284
Any Māori individual	0.153
Migrants	0.342
Rural location	0.095
Other urban location	0.386
Major urban location	0.518
Highest qualification is certificate level 3 or lower	0.395
Highest qualification is certificate level 4-6	0.296
Highest qualification is a Bachelor degree or higher	0.309
HES year 2006/07	0.174
HES year 2009/10	0.188
HES year 2012/13	0.181
HES year 2015/16	0.214
HES year 2018/19	0.242

Source: Household Economic Survey 2006/07, 2009/10, 2012/12, 2015/16, 2018/19
Notes: *Sample size has been RR3'ed to protect confidentiality; all proportions have been calculated based on RR3 counts. #Standard deviation in parentheses

Appendix Table 4: Vector Error Correction estimates

Dependent variable		ln(Petrol)	ln(price)	ln(GDP)
Transform		S1	S1	S1
		(1)	(2)	(3)
		(a) Error correction equations		
CE	L	-0.138***	-0.0465	-0.0242
		(0.0340)	(0.0716)	(0.0174)
ln(Petrol)	LS	-0.317***	0.324*	-0.00281
		(0.0728)	(0.153)	(0.0373)
ln(price)	LS	-0.00196	0.155*	-0.0153
		(0.0366)	(0.0771)	(0.0187)
ln(GDP pc)	LS	-0.0323	-0.308	0.0121
		(0.150)	(0.315)	(0.0766)
N		182	182	182
R-squared		0.194	0.0392	0.104
		(b) Cointegrating equation		
ln(Petrol)			1	
			(.)	
ln(price)			0.384***	
			(0.058)	
ln(GDP pc)			0.035	
			(0.053)	
			11.813	
			(.)	

Appendix Table 5: Quadratic distributed lag model

Dependent variable		Quadratic	Quadratic with IV
		S.ln(Petrol)	S.ln(Petrol)
ln(price)	S	0.497	6.960
		(1.028)	(9.511)
	LS	1.358	-10.62
		(0.981)	(10.02)
	L2S	-0.288	7.514
		(0.926)	(15.14)
	L3S	0.840	-5.353
		(1.196)	(8.786)
	L4S	-0.728	10.68
		(1.227)	(9.105)
ln(price)^2	S	-0.0574	-0.659
		(0.0964)	(0.896)
	LS	-0.124	0.993
		(0.0916)	(0.939)
	L2S	0.0188	-0.713
		(0.0861)	(1.419)
	L3S	-0.0817	0.496
		(0.112)	(0.819)
	L4S	0.0700	-1.005
		(0.117)	(0.854)
ln(GDPpc)	S	0.398*	0.155
		(0.164)	(0.364)
	LS	-0.239	0.00628
		(0.190)	(0.306)
	L2S	0.0296	0.00774
		(0.192)	(0.311)
	L3S	0.239	0.296
		(0.168)	(0.328)
	L4S	-0.255	-0.378
		(0.145)	(0.258)
	N	179	179
	R-sq	0.192	-0.922
	Adj. R-sq	0.118	-1.099

Notes:

- Dependent variable is log petrol consumption per capita
- Robust standard errors in parentheses. * p<0.05, ** p<0.01, *** p<0.001
- IV stats: UnderID (Anderson CanCorr = 4.6, p-value=0.03); weakID (Cragg-Donald Wald F = 0.3)