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Short-run and Long-run Gasoline Demand Elasticities: A Case Study of Australia

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Abstract – *This study focuses on examining gasoline demand elasticities in Australia. The short-run and long-run elasticities are estimated based on the panel data from seven capital cities in Australia between 2010 (quarter 3) and 2017 (quarter 4). The paper exploits single-equation panel data results, instrumental variable (IV) estimates, and distributed lag method to demonstrate the short-run and long-run effects of various factors on gasoline demand. We use the world crude oil price as an instrumental variable. The research results indicate short-run and long-run price elasticities of -0.11 and around -0.16 to -0.18, respectively. Although the conclusion is not able to be drawn about the long-run income elasticity of gasoline demand, the short-run finding of 1.35 shows that gasoline demand is income elastic. These findings indicate that the Australian government should increase the amount of gasoline stockpile and inform relevant tax policies on gasoline apart from emission taxes.*

Keywords – *Australia, gasoline demand, panel data, price elasticity, the world oil price.*

1. INTRODUCTION

In recent years, Australia has not met the international requirement in gasoline stocks. Australian petroleum as a share of the total Australian energy mix supply accounted for 51% and 39% in 1974-75 and 2011-2012, respectively [1]. Oil reserves in Australia were currently sitting around 20-30 days compared to the 91 days, which was the International Energy Agency's (IEA's) benchmark [2]. At the same time, Australian petroleum use has risen by 2% per year over the last decade [3]. This situation gave rise to a debate about whether the Australian Government should increase its gasoline stockpile in the next few years. Therefore, the responsiveness of gasoline demand to the change in retail gasoline price and income always received a great deal of attention from economists.

In this paper we focused on examining the expected responses of gasoline demand to given scenarios of the change of income and gasoline price in Australia. From these experimental viewpoints, this research was expected to indicate two clear statements. First, the research findings would be evidence-based to demonstrate a specific argument to the debate about the current status of gasoline reserve. The market-based predictable patterns could be useful to calculate approximately the amount of gasoline stock requirements and inform the development of approaches to curtailing consumption. Second, this comprehensive assessment was predicted to provide robust evidence-based for the Australian government to impose the up-to-date policy implications such as tax policies to control rising gasoline consumption.

The plots in Figure 1 and Figure 2 below described the possible linkages between price and consumption in the Australian gasoline market. The monthly time-series data of the average pump price for gasoline and automotive gasoline consumption in Australia were used to plot Figure 1. In this figure, logarithm terms of both price and consumption indicated a broad range. The fitted line plotted the appearance of the automotive gasoline demand curve. This downward-sloping curve indicated that lower average retail gasoline prices were associated with higher automotive gasoline consumption, holding other variables constant.

Figure 2 showed the time variation in the average pump price for gasoline and automotive gasoline consumption during the period 2010:M7 - 2017:M12 based on the Australian monthly datasets. The figure indicated that both retail gasoline prices and gasoline consumption were stable during this period. This suggested that the response to price might well be very inelastic. However, it still identified the negative response of gasoline consumption to the change in the price level. For example, during the first few months of 2015, when the gasoline price fell slightly, Australian automotive gasoline consumption increased gradually.

Given this background information about the Australian gasoline market, retail price and income elasticities in both the short-run and the long-run would be examined by using quarterly panel data models of seven capital cities in Australia during the period 2010 (quarter 3) and 2017 (quarter 4) (2010: Q3 - 2017: Q4) and a monthly dataset for the period 2010: M7 - 2017: M12. The main contribution of this paper was its use of the world crude oil price instrumental variable, which was chosen from supply-side and exogenous control variables to solve the potential endogeneity problem. Therefore, the findings were expected to provide strong evidence to forecast the increase of Australian gasoline demand in the next few years.

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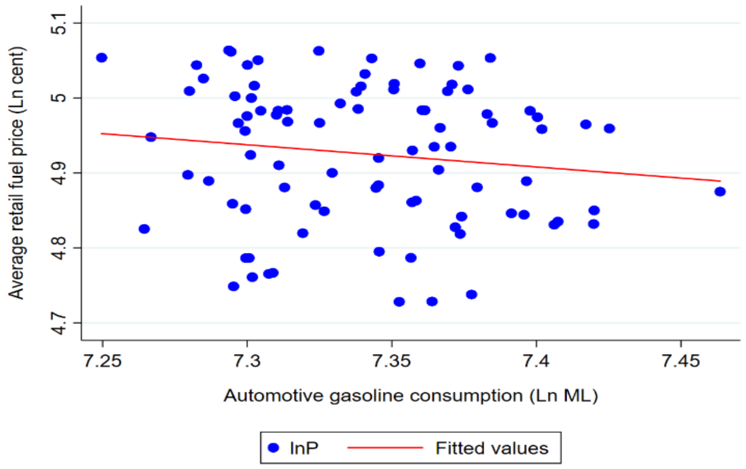

Fig. 1. Average retail gasoline price and automotive gasoline consumption in Australia between 2010 (month 7) and 2017 (month 12) (2010: M7 – 2017: M12).
The average retail gasoline price and automotive gasoline consumption were taken in logarithm terms with the unit measurements were ln cent and ln ML, respectively. The logarithm of the average retail gasoline price was denoted by lnP.

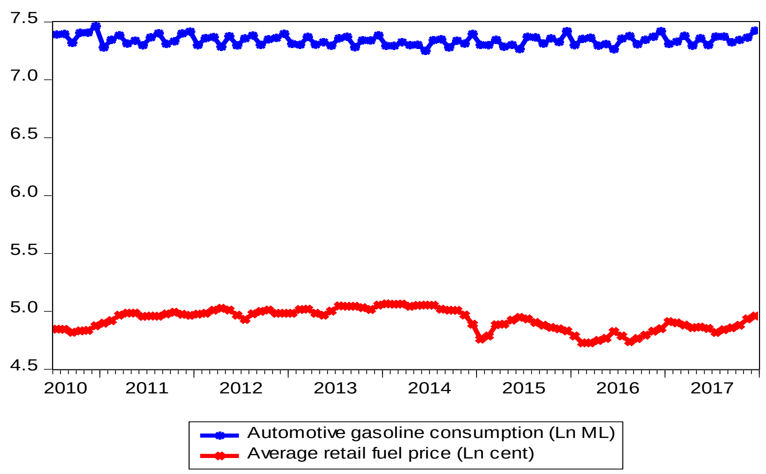

Fig. 2. The time variation of retail gasoline price and automotive gasoline consumption during the period 2010: M7 – 2017: M12.
The average retail gasoline price and automotive gasoline consumption were shown in logarithm terms.

The rest of the paper was structured as follows. The rationale for the research analysis was drawn in Section 2, followed by the description of data in Section 3 and the methodology in Section 4, respectively. Section 5 showed empirical results, and Section 6 compared the estimation result with previous literature. Concluding remarks and policy implications were in Section 7.

2. THE RATIONALE FOR THE RESEARCH ANALYSIS

Many detailed studies of gasoline use, gasoline price, and economic growth have been conducted. Some studies have estimated gasoline demand based on surveys and static models, such as [4] and [5]. Price and income elasticities of petroleum product demand have also been investigated using time series cointegration and dynamic panel models [6], [7], [8]. The findings of these papers were summarized below.

Graham and Glaister [4] conducted surveys to evaluate the short-run and long-run elasticities of automobile gasoline demand globally. These surveys highlighted the difference between short-run and long-run price and income elasticities of gasoline use. Specifically, while the range of short-run price elasticities was between -0.2 and -0.3, in the long-run this magnitude was between -0.6 and -0.8. Short-run and long-run income elasticities were typically positive and in the range of 0.35_0.55 and 1.1_1.3, respectively.

Dahl [5] summarised the gasoline and diesel elasticities from existing studies to investigate income and price elasticities of gasoline demand across countries. This study using a static model identified some patterns from the historical work. Price elasticities were likely to be higher when diesel gasoline and gasoline prices were high. Income seemed to be less elastic with an increase of income per capita for diesel gasoline, whereas as income per capita for gasoline went up, income became more elastic. However, [5] assumed that price elasticities could be considered in the long-run from static models, but historical research had not been conducted to support her assumption; therefore, this study may have biased long-run parameters. Additionally, the difference in price elasticities of the static model compared with non-stock model results means that conclusions about the long-run response were uncertain.

Using the same exploration of dynamic models but with a difference in data level, [6] and [8] came up with different conclusions. [6] used an aggregate dataset to estimate total demand elasticities for total gasoline and diesel products and the share of gasoline in total petroleum products in Indonesia. The result of these estimations showed that income elasticities were higher than petroleum price elasticities. These elasticities in both the short run and long run differed slightly in magnitude across the selection criteria used. Meanwhile, by disaggregating consumers in the United States into three different income quintiles, [8] concluded that the lowest income quintile experienced higher price elasticity than the middle and wealthiest quintiles. The price elasticities of rural households were lower than urban households based on the rebound effect. However, this research could not reach a conclusion about the response in gasoline demand between groups when income changes.

The local and national levels of gasoline per vehicle demand in Mexico were estimated and compared by using a dynamic panel generalised method of moments (GMM) and time series cointegration model [7]. This study confirmed the sign and change of elasticities found in the previous work. However, the magnitude of price elasticities had a lower range of -0.2 to -0.26 compared to the results from historical surveys of between -0.6 and -0.8. The difference in econometric models between this study and demand surveys may have affected the magnitude of income and price elasticities. [7] applied the formula used in [4] to derive state elasticities from national estimation results, but the results were statistically insignificant and biased downwards. The price variation in Mexican cities was violated with the assumption of constant price across regions developed by [4]. Therefore, instead of adding lagged dependent variables or difference GMM, instrumental variables, exogenous controls, and time trends should be included in the model to produce unbiased and reliable estimations. These additional terms would be explained in detail in the methodology section of this paper.

Although the issues in data and methodologies were strictly controlled to improve the significance and reliability of findings, these reviewed studies came up with different income and price elasticity values. The main problem was that elasticities varied significantly over time, depending on other economic factors, technology, or political changes. For example, most of these studies used the real gross domestic product (INC) to measure the income variable in the model, while Australian economic growth could be evaluated based on gross state product (GSP)[2]. Therefore, replicating the previous methodology to investigate price and income elasticities for gasoline demand in the context of Australian economies might not give expected results.

Moreover, to date, there has been no empirical research that exploited data disaggregated by states in the analysis of Australian domestic gasoline demand, price, and economic activities. [9] modelled the unleaded petrol price in four Australian capital cities (Adelaide, Brisbane, Melbourne, and Sydney) by applying asymmetric short-run dynamic models and cointegration tests. However, this study was very aggregate in terms of explaining asymmetric responses of petrol price adjustments either in the long-run equilibrium or short-run effects. Motivated by the important contributions of gasoline demand elasticity analysis and existing literature, this study attempted to investigate gasoline demand elasticities in Australia. The paper mainly focused on estimating the short-run and long-run elasticities for gasoline demand in response to the retail price of gasoline and income. Concerning this primary purpose, the completed research should answer the question: how did gasoline demand respond to changes in retail price and income in Australia?

3. RESULTS AND DISCUSSION

3.1 Variable Specification and Data Sources

This study was conducted by estimating panel data models of seven Australian states/territories (New South Wales (NSW), Victoria (VIC), Queensland (QLD), South Australia (SA), Tasmania (TAS), Western Australia (WA), and the Northern Territory (NT))[3] during the period 2010:Q3 - 2017:Q4. The variable specification and relevant data sources were specified as follows:

- Automotive gasoline consumption (E) was measured in million litres (ML) and the data was collected from Australian Petroleum Statistics (APS) reports.
- The average retail price for gasoline (P) was measured in AUD cents. This nominal series was obtained from [10]. The quarterly value was calculated by using the average over the three months in a quarter.
- In this paper, a household's final consumption expenditure (2016 - 2017 prices) was a proxy for state income (INC). The unit measurement of this variable was AUD millions. Log INC measured the income effect of states. These statistics were obtained from the Australian Bureau of Statistics (ABS) [11], [12], [13].
- Three control variables were used: the estimated resident population (PoP) – persons, the unemployment rate (UP) – percentage and

[2] According to the Northern Territory Government (2018) [14] definition, "Gross state product is a measure of value-adding that occurs in an economy". GSP was calculated by an average of expenditure (GSP (E)), production (GSP (P)), and income (GSP (I)).

[3] The Australian Capital Territory (ACT) was not estimated in this paper because data about ACT fuel use was already included in the NSW total.

temperature (TEM) – oC. The data for the first two variables were obtained from ABS data. The source for the temperature data was the Australian Bureau of Meteorology [15].

- The world crude oil price (WOP), measured in US dollars per barrel, were used as an instrumental variable. The paper also used the data from [16].
- Time trend: in the quarterly dataset, this starts at 0 in the third quarter of 2010 and increased by 1 for every subsequent time step. In the monthly data, this began from 0 in July 2010 and increased by 1 for each following month.

The summary statistics of variables in logarithm terms were summarised in Table A1 in the appendix. Additionally, the consumer confidence index (CCI) was added to conduct a robustness check.

The consumer confidence index was collected from [17]. The quarterly data was calculated by using the average over the three months of the quarter.

3.2 Unit Root Testing

Conducting unit root tests was a step that came before choosing a functional form. There were two steps to this process, as follows:

Step 1: Running a regression of the main variable on the quarter of year dummies, and then taking the residual value.

Step 2: Regressing the Im-Pesaran-Shin [18] unit root test for dynamic panel data on the residual term. The lag length was chosen based on the Akaike information criterion (AIC).

The results of five key variables (log automotive gasoline consumption, log average retail price for gasoline, log income, log population, log unemployment rate) were shown in Table 1. These tests showed that the null hypothesis (time-series data contains the unit root) could be rejected, and therefore all of the key variables were stationary at a 1% significant level. Given the evidence from the Im-Pesaran-Shin test, estimation of the model in levels was appropriate, and was the approach adopted in this study. However, the estimated model at a level could not provide results that distinguish between short-run and long-run elasticities. Therefore, estimations at first differences were conducted to obtain the results for demand elasticities in the short run. Levels models were then used to test for long-run effects.

Table 1. Im-Pesaran-Shin unit root tests.

Residual for	Observations	Lags	Test statistic	p-value
Ln automotive gasoline consumption (million litres)	210	1	-1.2e+02	0.00
Ln average retail price for gasoline (AUD cent)	210	1	-12.75	0.00
Ln income (AUD million)	210	1	-15.04	0.00
Ln population (persons)	210	1	-73.99	0.00
Ln unemployment rate (percent)	210	1	-16.64	0.00

4. METHODOLOGY

4.1 Model Specification

A partial energy demand model was used for the analysis in this paper. This aggregate (total) demand model was mainly determined by the total income (Gross Domestic Product (GDP)) and the relative price of energy demand ($P(E_t)$). However, because the state income in Australia is measured separately, income variable (GDP) was replaced by INC to be appropriate with the available data. Therefore, the general form to estimate the gasoline demand elasticities in this paper was:

$$E\ (t) = \alpha * INC^{\beta}\ (t) * P^{\varphi}\ (Et) \quad (1)$$

Where E (t) was the aggregate energy demand (in physical units); INC (t) was the real state final demand of households' final consumption expenditure; P (Et) was the relative price of energy; α was a constant determining the general level of demand; and β and φ represented the income and price elasticity, respectively [19]. Then taking logarithms of both sides of Equation 1 and adding an error term obtained:

$$\ln E\ (t) = \ln\alpha + \beta \ln INC\ (t) + \varphi \ln P\ (Et) + \mu\ (t) \quad (2)$$

The purpose of transforming variables into natural logarithms was to reduce the problem of heteroskedasticity and obtain the value of the growth rate by taking the first difference logarithms of relevant variables [20].

The estimated resident population (PoP), unemployment rate by state (UP)[4], temperature (TEM) and a time trend and quarter of year dummies were also included in the model as control variables. These control variables tended to be exogenous to automotive gasoline consumption and did not affect gasoline use through the state growth rate channel. Taking logarithms of these variables and adding them into Equation 2 gave:

$$\begin{aligned} \ln E\ (t) &= \ln\alpha + \beta \ln INC\ (t) + \varphi \ln P\ (Et) \\ &+ \varepsilon_1 \ln PoP\ (t) + \varepsilon_2 \ln UP\ (t) + \varepsilon_3\, TEM\ (t) \quad (3) \\ &+ \varepsilon_4\, T + \varepsilon_5\, D\ (i) + \mu\ (t) \end{aligned}$$

4.2 Instrumental Variable Approach

There were several reasons why it was crucial to consider the endogeneity problem. Firstly, the problem

[4] In terms of the income perspective, the inclusion of UP in the model as a control variable might significantly affect the value of income elasticities of fuel demand because the unemployment rate impacted strongly on the income variable. However, after checking the estimated model with and without the UP variable, the results in Table 3 and Table A2 showed that UP had a modest effect on the income elasticities. Therefore, the paper argued that it was safe to control for UP in the model.

of joint determination between price and quantity could result in an endogeneity problem. This meant that independent variables could be correlated with the error term in the estimated model. Secondly, gasoline demand was expected to affect the retail gasoline price; the reverse causality among dependent and explanatory variables like this might lead to potential endogeneity. As a result, the paper remained uncertain whether the panel data could provide consistent estimates. Moreover, there were also other potential sources of endogeneity like omitted variable bias, sample selection bias, or measurement error for independent variables.

To deal with the endogeneity issue, this study used the logarithm of the world crude oil price (WOP) as an instrumental variable. Since Singapore was the main exporter of Australian automotive gasoline, the retail gasoline market price was mainly decided based on Singapore's gasoline export prices. Singapore wholesale export prices, in turn, relied strongly on the world crude oil price [21]. Therefore, the world crude oil price was used as an IV for Australian retail gasoline prices. It was likely that threats to exclusion restriction might still exist. For example, if there was a correlation between the world crude oil price and global consumer sentiment or stock market performance, this might be relevant for local gasoline use. However, a supply-side IV and the use of exogenous controlled variables were able to break the correlation between the world crude oil price and other variables in the model. As a result, the IV exclusion restriction meant that the IV could be treated as an exogenous variable, and it only affected automotive gasoline consumption via the retail gasoline price [22]. This paper then used the two-stage least squares (2SLS) method to estimate the model (3).

4.3 Distributed Lag Model

Applying distributed lags allowed for the determination of the dynamic influence of automotive gasoline consumption response to the change in retail gasoline price and income, respectively. Lagged income and retail price variables were included in the model (3) to obtain the distributed lag model as the model (4). This approach employed fixed effect estimations, a quarter of year dummies, and single-equation regressions. The sum of the lagged coefficients provided the long-run value of gasoline demand elasticities. The use of the distributed lag (ARDL) model also helped to reduce the problem of endogeneity because residual correlation might not appear in the dynamic single-equation system.

$$\ln E\,(t) = \ln \pounds + \Omega\sum_{l=0}^{L} lnGDP\;(t-l) + \pi\sum_{l=0}^{L} lnP\;(E, t-l) + \delta_1 \ln PoP\,(t) + \delta_2 \ln UP\,(t) + \delta_3\, TEM\,(t) + \delta_4\, T + \delta_5\, D(i) + \mu\,(t) \qquad (4)$$

After estimating model (4) using the ARDL model, π and Ω were the long-run retail price and income elasticities of gasoline use. π was also expected to be negative, as the increase in the retail gasoline price would reduce the amount of gasoline used in the long run. Meanwhile, a long-run income elasticity (Ω) greater than 0 was good. The long-run gasoline demand elasticities were expected to have a larger absolute value than the short-run demand elasticities. The main reason for this was that the consumer needed to take time to find some other kind of energy to substitute for gasoline. Therefore, in the short run, consumers would keep using automotive gasoline or slightly reduce their consumption.

5. EMPIRICAL RESULTS

5.1 Panel Data Estimation Results

The estimation began by conducting panel data estimation based on fixed effects and first differenced (within) regressions of the model (3)[5]. Because of the large variation in the value of households' final consumption expenditure, the INC variable explained almost the variation in the dependent variable so that the R square was very high. Therefore, in the fixed effects regression, the value of within R square in fixed effect was demonstrated in the result Table 2. The reported within R square interpreted the goodness of fit, relying only on the regression of each state's fixed effect, which avoided the variation between states' information.

Table 2 presented the panel data estimation of the model (3). As the fixed effect estimation held for the correlation among unobserved effects and the independent variables, the consistent estimates of fixed-effect coefficients in column (1) showed the negative response of gasoline demand to the retail gasoline price as well as the positive relationship between gasoline demand and a state's income. Although the gasoline price coefficient was insignificant at the tested levels, the gasoline price elasticity of -0.07 indicated that when the retail gasoline price increased by 1%, the total gasoline demand went down by 0.07%, holding income, the estimated population, the unemployment rate, and temperature constant. The income elasticity of 0.93 showed the positive and significant effect of income on gasoline demand. This meant that it was not possible to reject the null hypothesis that the income elasticity equals +1, reflecting a quite substantial increase in gasoline consumption as income went up. Notably, the reported standard errors of these results were robust to heteroscedasticity.

The panel estimation included the estimated result of the first differences in column (2). As per the earlier explanation, the coefficient of this result showed the short-run demand elasticity. The short-run retail price elasticity was larger than the fixed effect price coefficient and significantly different from zero. As expected, an increase in pump gasoline price reduced the amount of gasoline consumption, and the price elasticity tended to be more inelastic in the short run. Conversely, the absolute value of short-run income elasticity was much higher than the results in column (1) as well as distinguishable from +1, demonstrating a strong effect of income on automotive gasoline consumption in the short run.

Short-run elasticity also indicated the effects of

[5] The paper also estimated model (3) by using ordinary least squares (OLS) for each state. The results of these regressions were shown in Table A3.

other factors on gasoline consumption. Firstly, the size of the population positively and significantly impacted the total gasoline consumption. Secondly, as the temperature got higher, people tended to consume more gasoline. This result made sense because hot weather increased the use of a car's air conditioning, drivers tended to roll down the windows, or people might go out more, thus gasoline consumption increased. In terms of the unemployment rate, even though the coefficient was insignificant, this variable still indicated a positive relationship with gasoline demand. Unemployed people usually bought gasoline-inefficient cars because these vehicles were relatively cheap. Gasoline inefficient vehicles conversely consumed more gasoline and therefore pushed up gasoline demand.

Table 2. Panel data estimation results of model (3) using quarterly data.

Dependent variable: Ln automotive gasoline		Dependent variable: First differenced ln automotive gasoline	
	(1) Fixed effect		(2) First differenced
Ln price	-0.07	First differenced Ln price	-0.10
	(0.06)		(0.03)**
Ln income	0.93	First differenced Ln income	1.35
	(0.36)**		(0.19)***
Ln population	1.24	First differenced Ln population	5.14
	(0.89)		(1.55)**
Ln unemployment rate	0.09	First differenced Ln unemployment rate	0.05
	(0.08)		(0.03)
Temperature (^{0}C)	0.01	First differenced Temperature (^{0}C)	0.01
	(0.01)		(0.00)*
Time trend	-0.01	Time trend	0.00
	(0.00)***		(0.00)
The quarter of year dummies	Yes	The quarter of year dummies	Yes
Constant	-21.67	Constant	-0.12
	(9.96)***		(0.03)***
R^2	0.46	R^2	0.65
Number of observations	210	Number of observations	203

Notes: Robust standard errors were in parentheses. Within R^2 in a fixed-effect model represented the ability of explanatory variables to explain the change of the dependent variable within each of the states over time. The coefficient of the quarter of year dummies was not reported. The temperature variable was not a logarithm. *, **, *** reflected statistical significance at 10%, 5%, and 1%, respectively.

5.2 Instrumental Variable Results

Table 3 represented the gasoline demand elasticities, both at the level and the first difference, when the IV strategy was used. The panel estimated with the world crude oil price as an IV indicate that a higher retail gasoline price significantly reduced the amount of gasoline demand in the short run, as shown in column (2). The magnitude of the retail price for gasoline elasticity equaled -0.11. This value was slightly higher than the absolute value of price elasticity in column (2) Table 2. The use of the instrumental variable pushed out the endogenous part of the retail gasoline price variable and therefore helped to obtain a consistent estimation result for price elasticity. Comparing the income elasticities in column (1) Table 3 and column (1) Table 2, as well as column (2) Table 3 and column (2) Table 2, these values were similar. This comparison once again confirmed the positive and significant effect of income on gasoline demand. Therefore, short-run income elasticity was calculated to have a magnitude of + 1.35.

Table 3 also showed the values of the first stage, including the coefficient for instrument and the instrument F statistic. Positive coefficients for the instrument both at the level and the first difference indicated that Australian retail gasoline prices were significantly and positively correlated with the world crude oil price. In reference [23], tests provided a strong indication for rejecting the null hypothesis at all IV specification levels. Therefore, the world crude oil price was strong enough to use as an IV.

5.3 Long-run Demand Elasticities

The ARDL method was applied to estimate the long-run gasoline demand elasticities in the model (4). The distributed lag estimated with the time trend and the quarter of year dummies are shown in Table 4. Lag price terms were added for each second quarter until lag t-5. The distributed lag estimates were tested similarly for lagged income but the long-run income elasticities were statistically insignificant and therefore this paper did not include them.

Table 3. IV estimation results.

Dependent variable: Ln automotive gasoline		Dependent variable: First differenced ln automotive gasoline	
	(1)		(2)
	IV at level		IV regression at first differenced
Ln retail gasoline price	-0.08	First differenced Ln retail gasoline price	-0.11
	(0.06)		(0.06)*
Ln income	0.93	First differenced Ln income	1.35
	(0.39)**		(0.25)***
Ln population	1.26	First differenced Ln population	5.13
	(0.48)***		(2.28)**
Ln unemployment rate	0.10	First differenced Ln unemployment rate	0.05
	(0.05)*		(0.04)
Temperature (^{0}C)	0.01	First differenced temperature (^{0}C)	0.01
	(0.00)*		(0.00)***
Time trend	-0.01	Time trend	0.00
	(0.00)***		(0.00)
The quarter of year dummies	Yes	The quarter of year dummies	Yes
First stage		First stage	
Coefficient for instrument	0.28	Coefficient for instrument	0.31
Instrument F statistic	827.73	Instrument F statistic	316.17
R^2	0.46	R^2	0.65
Number of observations	210	Number of observations	203

Notes: Robust standard errors were in parentheses. Coefficients of the quarter of year dummies and constant were not shown. The value of R^2 represented the power of the explanatory variables in the model. The model was instrumented by the log of the world crude oil price. *, **, *** reflected statistical significance at 10%, 5%, and 1%, respectively.

The results in column (6) Table 4 showed a value of long-run retail gasoline price elasticity of -0.18 when lags back to t-5 were included (statistically significant at the 5% level). The distributed lag price elasticity was slightly higher than the price elasticity of -0.07 from the result of the fixed effects. The average long-run price elasticity varied from -0.16 to -0.18 depending on the number of lags added. As expected, the absolute value of long-run gasoline price elasticity was higher than the short-run elasticity. The -0.16 to -0.18 points were statistically different from -1. The estimates indicated that gasoline demand was likely to be price inelastic both in the short run and long run. Specifically, total gasoline demand reduced by proportionately less as the retail gasoline price increases.

5.4 Robustness Check

As discussed in the literature review section, gasoline demand elasticities varied greatly depending on economic factors. Therefore, the paper also investigated a dynamic panel monthly dataset from 2010: M7-2017: M12. The income variable, previously represented by households' final consumption expenditure (INC), was changed to the consumer confidence index (CCI). The use of CCI allowed the paper to deal with two problems. Firstly, the demand elasticity results obtained from the model with CCI might provide strong evidence to support the paper's findings. Secondly, the INC dataset was only collected every quarter, while CCI time-series was available monthly, and therefore suitable for the monthly panel dataset. Monthly time-series data for the estimated population variable was not available, but the population was a slowly evolving variable which did not go up and down sharply every month. The paper, therefore, interpolated and extrapolated the monthly data from the quarterly population time-series.

Table 5 showed the result of IV estimations of monthly panel data at the level in column (1) and the first difference in column (2). In terms of gasoline price elasticity, gasoline demand elasticities seemed to be unaffected immediately by the change in retail gasoline price. However, after one period, this negative effect of gasoline price appeared quite clear as shown in column (2). The short-run price elasticity of the retail gasoline price of -0.20 was statistically significant at the 5% level. The absolute value in this estimate was higher than the short-run elasticity shown in Table 4. Gasoline demand responded positively but insignificantly to the change in consumer confidence index both at the level and the first difference.

Additionally, the short-run income elasticity in column (2) Table 5 was lower than the short-run income elasticity of 1.35 in column (2) Table (3). This indicated that the INC effect on gasoline demand tended to be stronger than the consumer confidence index effect. However, the whole model remained the same sign and trend of effects. Based on the result in column (2) Table 5, the paper's conclusions remained in line with those supported by the results presented above. Additionally, most of the estimations have a relatively high value of R^2. These R^2 values show the power of the independent variables in explaining the model.

Table 4. Distributed lag results by estimating model (3) using quarterly data.

Dependent variable: ln automotive gasoline consumption	(1)	(2)	(3)	(4)	(5)	(6)
Ln retail gasoline price	-0.07	-0.02	-0.01	0.00	-0.02	-0.03
	(0.05)	(0.07)	(0.07)	(0.07)	(0.07)	(0.07)
Lag 1		-0.04	0.07	0.06	0.07	0.07
		(0.07)	(0.09)	(0.09)	(0.09)	(0.09)
Lag 2			-0.13*	-0.01	-0.01	-0.00
			(0.07)	(0.09)	(0.09)	(0.09)
Lag 3				-0.16**	-0.03	-0.03
				(0.07)	(0.09)	(0.09)
Lag 4					-0.17**	-0.09
					(0.07)	(0.09)
Lag 5						-0.10
						(0.07)
Ln income	0.93***	0.84**	1.02***	0.95***	0.81**	0.63*
	(0.34)	(0.33)	(0.34)	(0.35)	(0.34)	(0.34)
Ln population	1.24***	1.31***	1.24***	1.30***	1.43***	1.62***
	(0.47)	(0.45)	(0.45)	(0.45)	(0.45)	(0.46)
Ln unemployment rate	0.09**	0.13***	0.16***	0.20***	0.21***	0.21***
	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)
Temperature (^{0}C)	0.01***	0.00*	0.00*	0.01**	0.01**	0.01**
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Time trend	-0.01***	-0.01***	-0.01***	-0.01***	-0.01***	-0.01***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
The quarter of year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Constant	-21.66***	-21.69***	-22.50***	-22.48***	-22.80***	-23.72***
	(4.81)	(4.65)	(4.70)	(4.79)	(4.90)	(5.09)
R^2	0.465	0.472	0.477	0.502	0.527	0.528
Number of observations	210	203	196	189	182	175
Long-run price elasticity	-0.07	-0.06	-0.07	-0.11*	-0.16**	-0.18**

Notes: Standard errors were in parentheses. Coefficients of the quarter of year dummies and constant were not shown. The value of R^2 represented the power of the explanatory variables in the model. The long-run price elasticities were obtained from the sum of coefficients for each retail gasoline price column. *, **, *** reflected statistical significance at 10%, 5%, and 1%, respectively. As the number of lags increased, the number of observations reduced because of missing data.

Table 5. Robustness test results based on the monthly dataset.

Dependent variable: Ln automotive gasoline	(1) IV regression at level	Dependent variable: First differenced ln automotive gasoline	(2) IV regression at first differenced
Ln price	-0.11	First differenced Ln price	-0.20
	(0.04)***		(0.10)**
Ln consumer confidence index	0.02	First differenced consumer confidence index	0.10
	(0.08)		(0.08)
Ln unemployment rate	0.08	First differenced Ln unemployment rate	0.03
	(0.03)***		(0.02)
Ln population	2.20	First differenced Ln population	14.28
	(0.19)***		(4.21)***
Temperature (^{0}C)	0.01	First differenced Temperature (^{0}C)	0.00
	(0.00)***		(0.00)
Time trend	-0.00	Time trend	0.00
	(0.00)***		(0.00)
The month of year dummies	Yes	The month of year dummies	Yes
First stage	0.28	First stage	0.24
	(0.00)***		(0.00)**
R^2	0.47	R^2	0.63
Number of observations	616	Number of observations	609

Notes: Robust standard errors were in parentheses. Coefficients of the month of year dummies and constant were not shown. The value of R^2 represented the power of the explanatory variables in the model. The model was instrumented by the log of the world crude oil price. *, **, *** reflected statistical significance at 10%, 5%, and 1%, respectively.

There were still other omitted variables that were likely to affect the size of gasoline demand. However, these omitted variables would lead to serious problems related to model identification only if they were highly correlated with retail gasoline price (in single-equation panel estimates) or the world crude oil price instrumental variable (in IV estimates). The combination of strategies used in this paper, including the use of an IV and numerous controls (estimated population, the unemployment rate, temperature, time trend, a quarter of year dummies), together helped to confidently reach the consistent estimates of gasoline demand elasticities.

6. COMPARING THE ESTIMATION RESULTS WITH PREVIOUS LITERATURE

Previous studies commonly found the price inelastic of gasoline demand both in the short-run and long-run. [5] obtained short-run and long-run price elasticities of -0.10 and -0.33 respectively. This result was similar to [24] long-run price elasticity of -0.39 for gasoline demand in the United States as well as the short-run value of -0.13 and long-run of -0.20 for petrol demand elasticities in Australia. Reference [25] reported that gasoline demand elasticity results were different between countries like Spain, with -0.14 in the short run and -0.30 in the long run or short-run of -0.05 and, and Germany, with a long-run of -0.56 in Germany. They also concluded that Australia had a very inelastic response for transport gasoline with a short-run value of -0.05 and a long-run value of -0.18. The use of the distributed lag method to calculate the long-run price elasticities of seven Australian capital cities in this paper resulted in a higher absolute value for the short run but the same long-run value.

The short-run income elasticity in this paper was higher than the values found in the existing literature. [25] reported that the average short-run income elasticity of transport gasoline demand equaled 0.41 in 20 OECD countries. By summarising 101 previous studies on gasoline demand conducted between 1966 and 1997, [26] reported an average short-run income elasticity of around 0.47. [27] found an income elasticity of gasoline demand of 1.18 in India. Income elasticity of about 0.8 for gasoline was reported in Brazil [28]. The estimates in this paper also showed the difference in income elasticities depending on what variable was used to measure income. This finding again contributed to the board range of income elasticities displayed in the existing studies.

After comparing the research results, we recognized that our values of the short-run price and income elasticities were higher than these values in the previous literature. Some reasons led to this situation. First, to mitigate the problem of endogeneity, we exploited both the IV method and the ARDL model. As a result, this paper could control the possible sources of endogeneity and provide more consistent findings. Higher values of elasticities represented that consumers needed a longer time to adjust their amount of gasoline consumption even in the short run. Second, instead of using the total income (GDP) of Australia, we disaggregated this total income into state income and then applied a total energy demand model to estimate the values in this paper. Therefore, these higher values indicated clearly that consumers at the state level reacted slowly with the adjustment of price and income in the short run compared to at the country level. Last but not least, the values of elasticities were sensitive to the changes in economic factors so that the differences in the use of proxied variables led to significant varies in the estimated results.

7. CONCLUSION

This paper used panel data of seven capital cities in Australia to estimate short-run and long-run gasoline demand elasticities. Short-run price elasticity of -0.11 and long-run elasticity of -0.16 to -0.18 were reported in this study. These values fell somewhere between the values found in existing studies. The paper's results indicated that Australian consumers tended to be price inelastic both in the short and long term. As a result, when retail gasoline price in Australia increased, consumption reduced by proportionally less.

This study also suggested that gasoline demand in Australia was income elastic with a short-run income elasticity of 1.35. Therefore, income growth would result in more than proportional growth in gasoline demand holding other variables constant. Unfortunately, the estimates did not provide enough evidence to conclude the extent of long-run income elasticity.

In terms of research limitations, this paper mainly focused on the short-run and long-run gasoline demand elasticities in Australia, so there was scope for criticism. It was useful to employ within data to examine the change in gasoline demand by state and industry levels. However, the estimated results in this study provided strong evidence to consider the response of gasoline consumption under changes in retail price and income.

Based on these findings, the paper suggested two main policy implications. First, Australian consumers were quite vulnerable to changes in price as a result of price inelastic and thus the Australian government should consider increasing the amount of gasoline stockpile. When a downturn in the world gasoline supply occurred, the amount of the gasoline reserve could give consumers more time to find other kinds of substitute gasoline. Secondly, because the Australian bought quantity varied less with price, the total deadweight loss through taxation was smaller than in a more demand elastic case. Therefore, the gasoline demand elasticity resulted in this paper could be used to inform tax policy. However, tax policies related to emissions seem unsuitable. Even if an emissions tax leaded to an increase in retail gasoline prices, the inelastic price meant that the reduction in the consumed quantity was modest, resulting in only a small reduction in emissions.

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APPENDIX

Table A1. Summary statistics.

Variable		Mean	Standard Deviation	Min	Max	Observations
Log retail automotive gasoline demand	Overall		1.34	2.07	6.30	N = 210
	Between	4.80	1.44	2.38	6.18	n = 7
	Within		0.08	4.48	5.22	T = 30
Log average retail price for gasoline	Overall		0.10	4.68	5.16	N = 210
	Between	4.92	0.04	4.89	4.98	n = 7
	Within		0.09	4.70	5.10	T = 30
Log the households' final consumption expenditure (INC)	Overall		1.21	7.76	11.41	N = 210
	Between	9.86	1.30	7.87	11.27	n = 7
	Within		0.05	9.74	10.01	T = 30
Log the estimated population	Overall		1.20	12.35	15.89	N = 210
	Between	14.48	1.30	12.39	15.83	n = 7
	Within		0.03	14.41	14.56	T = 30
Log unemployment rate	Overall		0.21	0.87	2.08	N = 210
	Between	1.70	0.17	1.37	1.87	n = 7
	Within		0.13	1.20	2.10	T = 30
Log consumer confidence index	Overall		0.04	4.63	4.85	N = 630
	Between	4.74	9.59e-16	4.74	4.74	n = 7
	Within		0.04	4.62	4.85	T = 90

Table A2. Panel data estimation results of model (3) using quarterly data without the unemployment rate variable.

Dependent variable: Ln automotive gasoline		Dependent variable: First differenced ln automotive gasoline	
	(1) Fixed effect		(2) First differenced
Ln price	-0.04	First differenced Ln price	-0.09
	(0.05)		(0.05)**
Ln income	0.72	First differenced Ln income	1.38
	(0.33)**		(0.20)***
Ln population	1.52	First differenced Ln population	5.16
	(0.46)***		(1.88)***
Temperature (^{0}C)	0.01	First differenced Temperature (^{0}C)	0.01
	(0.00)***		(0.00)***
Time trend	-0.01	Time trend	0.00
	(0.00)***		(0.00)
The quarter of year dummies	Yes	The quarter of year dummies	Yes
Constant	-23.61	Constant	-0.12
	(4.80)***		(0.02)***
R^2	0.45	R^2	0.64
Number of Observations	210	Number of Observations	203

Notes: Standard errors were in parentheses. The coefficient of the quarter of year dummies was not reported. *, **, *** reflected statistical significance at 10%, 5%, and 1%, respectively.

Table A3. OLS results by states.

Dependent variable: Ln automotive gasoline							
	NSW	NT	QLD	SA	TAS	VIC	WA
Ln price	-0.05	0.19	-0.11	0.04	0.09	-0.05	-0.03
	(0.05)	(0.12)	(0.06)*	(0.04)	(0.07)	(0.05)	(0.05)
Ln income	0.69	-0.29	-1.45	0.17	0.13	1.61	0.29
	(0.80)	(0.63)	(0.87)	(0.50)	(0.50)	(0.59)**	(0.67)
Ln population	2.54	-2.17	1.34	-6.16	7.40	2.02	1.28
	(3.11)	(1.71)	(2.19)	(4.15)	(2.18)***	(1.99)	(1.07)
Ln unemployment rate	-0.16	-0.03	-0.20	-0.00	0.05	-0.02	0.04
	(0.07)**	(0.06)	(0.07)***	(0.04)	(0.06)	(0.07)	(0.06)
Temperature (^{0}C)	-0.00	0.03	-0.01	0.00	-0.00	-0.00	-0.01
	(0.01)	(0.02)**	(0.01)	(0.00)	(0.01)	(0.00)	(0.00)
Time trend	-0.02	-0.01	0.00	0.01	-0.02	-0.02	-0.00
	(0.01)	(0.00)	(0.01)	(0.01)	(0.00)***	(0.01)**	(0.00)**
The quarter of year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	-40.29	29.99	1.82	90.53	-94.62	-41.63	-16.14
	(46.69)	(19.71)	(28.97)	(62.45)	(26.30)***	(29.72)	(9.49)
R^2	0.87	0.95	0.83	0.86	0.97	0.87	0.92
N	30	30	30	30	30	30	30

Notes: Standard errors were in parentheses. The coefficient of the quarter of year dummies was not shown. *, **, *** reflected statistical significance at 10%, 5%, and 1%, respectively. As the number of lags increase, the number of observations reduced because of missing data.