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Keywords

Unleaded petrol prices; Australia; Asymmetric ECM models

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JEL classifications: C13, C51, D40, L11.

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1. Introduction

For many Australians petrol expenses constitute a substantial part of their fortnightly income and petrol price rises have a direct, and appreciable effect on their standard of living (Australian Competition and Consumer Commission Inquiry, ACCC, 2007). Valadkhani and Mitchell (2002) have examined the expected impact of petrol price rises on inflation. Although they found that the Australian economy is less vulnerable to oil price rises now than it was in the 1970s, the distributional impacts of price rises are more pronounced on poor families. They estimate that, if petrol prices are doubled, ceteris paribus, the rate of inflation accelerates by an additional 2 per cent on the top of what otherwise would have prevailed in the economy. Their results clearly indicate that the transport and agricultural sectors would mostly bear the cost of this price rise and the price rises are regressive in their impact (Valadkhani & Mitchell 2002). Therefore, it can be argued that petrol prices can significantly contribute to the rising rates of inflation in Australia.

Concern about Australia's petrol prices has been the subject of several inquiries (e.g. Australian Competition and Consumer Commission 1996, 2007; Industry Commission, IC 1994; Queensland Parliament 2006). According to FuelWatch (2009), Tapis crude oil prices (not West Texas Intermediate, which is the US market benchmark) and the Singapore price of Mogas 95 petrol are the major supply-side determinants of Australia's petrol prices[1]. The terminal gate prices usually make up around 95 per cent of pump prices. The wholesale price is typically based on a rolling average of: the spot price for the Singapore Mogas 95 unleaded petrol, the allocated shipping cost from Singapore to Australia, insurance, wharfage cost, and conversion from US dollars to Australian dollars. The Singapore price of petrol plus shipping costs and Australian taxes constitute 95 per cent of the wholesale price of petrol (FuelWatch 2009). The major objectives of this paper are to answer (test) the following questions (hypotheses) for each of seven capital cities, for which disaggregated monthly price data are readily available: First, do unleaded retail petrol prices respond asymmetrically to external shocks such as changes in crude oil prices or international petrol prices? If crude oil prices and/or the Singapore benchmark petrol prices increase, will the Bacon's (1991) "rockets-and-feathers hypothesis" be applicable in the context of Australia? That is to say, will petrol prices "shoot up like rockets" in response to say positive oil price shocks and "float down like feathers" in response to price falls? In other words, will petrol prices respond quickly following a rise in the price of crude oil, but fall much slower to crude-oil price decreases? Second, when crude oil prices and/or the Singapore benchmark petrol price increase (due to external shocks), on average, how much does the retail price of petrol rise in various capital cities?

This paper provides an analytical framework for making more informed and objective assessments of the sources of Australia's unleaded petrol price fluctuations, resulting in greater efficiency and transparency of retail petrol market. Using an entirely different approach, this study systematically examines the magnitude and dynamics of petrol price responses to global macroeconomic influences. Although previous studies and surveys (undertaken or commissioned mainly by the ACCC) have already covered this topic, they do not provide answers to all of the questions indicated above. Enough disaggregated time series data are now available to enable a meaningful econometric analysis of this issue. This study will be the first independent (non-government) academic study which will systematically examine the asymmetric effects of changes in (a) Tapis

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[1] Mogas 95 unleaded petrol is considered to be the closest substitute for Australian regular unleaded petrol.

crude oil prices; and (b) the Singapore benchmark price. It identifies the major sources of asymmetric fluctuations in unleaded petrol prices by using threshold and asymmetric error-correction models. The proposed models in this study have been adopted in similar contexts in the literature (see for example Al-Gudhea, Kenc & Dibooglu 2007; Bachmeier & Griffin 2003; Borenstein, Cameron & Gilbert 1997; Chen, Finney & Lai 2005; Radchenko 2005) and provide useful policy-relevant frameworks that can be used to forecast petrol prices across various parts of Australia and to evaluate the potential outcomes of policies and external events on those prices.

To date, there is no publicised Australian study that includes all major petrol price determinants in one single dynamic model and investigates the significance of each variable in explaining asymmetry in the retail distribution process. For example, Reilly and Witt (1998) included both the price of crude oil and the exchange rate in the UK to test the competing explanations for the asymmetric response. In addition, according to the recent inquiry of the ACCC (2007), average Australian retail petrol prices broadly follow the movements in the Singapore benchmark price. Al-Gudhea, Kenc and Dibooglu (2007) argue that the crude oil price is a principal determinant of changes in petrol prices but there are several other major determinants such as the exchange rate and the Singapore benchmark price if a significant portion of petrol is to be imported. Previous studies have not included all of these factors together. The omission of such factors constitutes omitted variable bias and invalidates their policy conclusions.

Therefore, in order to avoid mis-specified models, it is of paramount importance to include all major determinants of petrol prices in a model. This relatively important issue seems to have been neglected in previous econometric analysis of the Australian petrol market. This paper examines the issue of petrol price asymmetries in regard to not only the crude price but also in relation to the Singapore petrol prices where all variables are expressed in *Australian currency*.

Empirical findings on price asymmetry for North American markets have been mixed and ambiguous. For example, Chen, Finney and Lai (2005) use switching thresholds in a cointegration model of price adjustment and find evidence of asymmetry not only in short- and long-run adjustment but also across the spot and future markets. Balke, Brown & Yu¨cel(1998); Borenstein, Cameron and Gilbert (1997); Galeotti, Lanza and Manera (2003) and Karrenbrock (1991) have examined the same issue and concluded that not only petrol price increases are passed on to the consumer faster than price decreases but also petrol prices respond asymmetrically to changes in oil prices. But on the other hand, several other studies (e.g. Bachmeier & Griffin 2003; Godby et al. 2000) are quite skeptical of this view, arguing for no evidence of asymmetry between petrol prices and crude oil prices. As stated above, little substantive empirical work has been conducted regarding the dynamic effects of a change in crude oil prices on Australia' retail petrol prices. This project for the first time will adopt the threshold and asymmetric error-correction models to resolve the ongoing controversy over whether retail unleaded prices rise more readily than they fall due to external shocks in the petroleum or foreign exchange markets.

The remainder of the paper is structured as follows: Section 2 discusses briefly the theoretical framework of the threshold cointegration analysis employed in the paper. Section 3 presents the sources and summary statistics of the data employed as well as the unit root test results. Section 4 presents the empirical econometric results. Finally the last section offers some concluding comments.

2. Theoretical Framework

Unlike other commodities, petrol prices are more changeable. Petrol stations may charge higher prices on some days of the week to offset the losses associated with deeply discounted days. In some locations prices follow a weekly cycle, whereby petrol is generally cheapest on Tuesdays (for example) and more expensive during weekends and at the start of public holidays[2]. How can we incorporate these stylised facts in our model? In order to exclude unnecessary noise associated with the day-of-the week effect and focus on major sources of petrol price rises, monthly data are used in this paper. The data include Tapis crude oil prices, Singapore petrol price and retail average petrol prices for seven capital cities (Adelaide, Brisbane, Darwin, Hobart, Pert, Melbourne and Sydney). The monthly data span from May 1998 to January 2009 totalling 129 observations. The long-run relationship between the retail petrol price (*p*) and its three major determinants has been specified in equation (1):

$$p_{jt} = \alpha_0 + \alpha_1 o_t + \alpha_2 s_t + \alpha_3 T_t + \varepsilon_{jt} \qquad (1)$$

where:

$p_{jt=}$ the natural logarithm of unleaded petrol price \$A (where *j* denotes one of the seven capital cities in Australia (j=1,2,…,7),

o_t=the natural logarithm of Tapis crude oil prices per barrel in \$A,

s_t=the natural logarithm of Singapore (Mogas 95) petrol prices in Australian cents per gallon, and

T_t is a time trend variable, where 1998M5=1 and 2009M01=129,

The estimated αs are the long-run coefficients, which are expected to be all positive.

It is important to recognise that "successive Commonwealth Governments since 1977 have adopted an import parity pricing policy to determine national pricing levels for all motor fuels. This means the domestic price for petrol in Australia is linked to international petrol prices to ensure local refiners will not sell their offshore to obtain higher prices (and potentially leave no fuel for the local market) (FuelWatch, 2009, p.1).

Let us now assume that all of the variables appearing on both sides of equation (1) are I(1). According to Engle and Granger (1987), the stationary residuals resulting from equation (1) could then form an error correction (*EC*) mechanism representing the short-run deviation from the long run equilibrium (if any). That is:

$$EC_{jt-1} = \underbrace{\hat{\varepsilon}_{jt-1}}_{\text{Deviation from the long-run path}} = \underbrace{p_{jt-1}}_{\text{Actual value}} - \underbrace{(\hat{\alpha}_0 + \hat{\alpha}_1 o_{t-1} + \hat{\alpha}_2 s_{t-1} + \hat{\alpha}_3 T_{t-1})}_{\text{Long-run path}} \qquad (2)$$

Standard cointegration tests implicitly assume a symmetric adjustment process but if petrol price adjustments are asymmetric or if prices are sticky in the downward direction, these tests can be mis-specified. In other words, the Engle-Granger (1987) type tests with a linear adjustment procedure will be inappropriate when the dynamic adjustment of prices in fact could follow a non-linear behaviour. If the Johansen (1995) cointegration trace test indicates that there is only one cointegrating vector, then the underlying adjustment dynamics of petrol prices in response to changes in exogenous variables can be captured by using the following threshold error-correction model (Enders and Granger, 1998, Enders and Siklos, 2001):

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[2] These weekly price cycles may be associated with supply management, with deep discounting arising, for example, immediately prior to the next delivery of fuel to the retailer, by the wholesaler.

$$\begin{aligned}\Delta p_{jt} = {} & \sum_{i=1}^{k} \beta_i \,\Delta p_{jt-i} + \sum_{i=0}^{k}\left[\gamma_i^+ \Delta o_{t-i}^+ + \gamma_i^- \Delta o_{t-i}^-\right] + \sum_{i=0}^{k}\left[\eta_i^+ \Delta s_{t-i}^+ + \eta_i^- \Delta s_{t-i}^-\right] \\ & + \left[I_t \theta_j^- EC_{jt-1}^- + (1-I_t)\theta_j^+ EC_{jt-1}^+\right] + \sum_{i=1}^{11} \varphi_i \, DUM_{it} + \beta_{j0} + e_{it}\end{aligned} \qquad (3)$$

where:

$\Delta o_{jt}^+ = max\left\{\Delta o_{jt}^+, 0\right\} \Rightarrow \Delta o_{jt}^+ = \Delta o_t$ if $\Delta o_{jt} \geq 0$ and $\Delta o_{jt}^+ = 0$ if $\Delta o_{jt} < 0$,

$\Delta o_{jt}^- = min\left\{\Delta o_{jt}^-, 0\right\} \Rightarrow \Delta o_{jt}^- = \Delta o_{jt}$ if $\Delta o_{jt} < 0$ and $\Delta o_{jt}^- = 0$ if $\Delta o_{jt} \geq 0$,

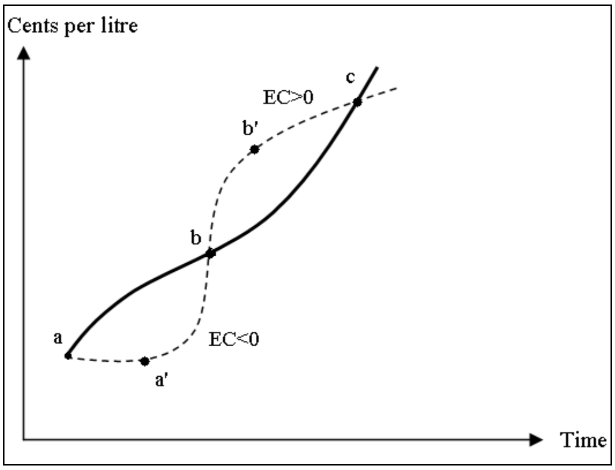
The variables Δs_t^+ and Δs_t^- are defined exactly in the same way as Δo_{jt}^+ and Δo_{jt}^-. Depending on whether the changes in explanatory variables are positive or negative (the threshold being zero), γ_i^+, γ_i^-, η_i^+ and η_i^- are the estimated short-run coefficients. However, it is not necessary to assume that the threshold value (τ) is always equal to zero for the θ feedback coefficient. In equation (4) I_t is the Heaviside indicator and τ or the optimum value of threshold are determined endogenously such that:

$$I_t = \begin{cases} 1 \text{ if } \hat{\varepsilon}_{\text{jt-1}} < \tau \\ 0 \text{ if } \hat{\varepsilon}_{\text{jt-1}} \geq \tau \end{cases} \qquad (4)$$

Therefore, θ_j^- and θ_j^+ are the different speeds of adjustment on the basis of the deviations from long-run. It should be noted that when the null of $\theta_j^- = \theta_j^+$ cannot be rejected, price adjustments are no longer asymmetric and this can be done by conducting a standard *F*-test. Given that the value of the threshold is unknown, its value (τ) should be empirically determined. A consistent value of the threshold can be found by undertaking a grid search by first sorting the $\hat{\varepsilon}_{\text{jt}}$ sequence in an ascending order as proposed by Enders and Siklos (2001). To have enough observations in each regime, I will look at each $\hat{\varepsilon}_{\text{jt}}$ within the middle 70% of the observations (excluding the first and last 15 per cent of the total number of observations) and whatever value of the threshold which yields the lowest residual sum of squares will be considered as a consistent estimate of the threshold.

Figure 1

Graphical definition of the asymmetric price adjustment



Note: The dotted and solid lines show the actual (short-run) and the long-**run price** of petrol, respectively.

The asymmetric price adjustment process can be better understood by using a graph. In Figure 1 if actual prices in the short-run (the dotted line) are below the long-run path (the solid line) say at a point between (a) and (b), retail distributors are more likely to increase their price immediately to the equilibrium level. Thus, a higher relative speed of adjustment (or the feedback coefficient) is expected. On the other hand, if the short-run price is above the long-run path, retail suppliers are more likely to keep their price at that level as long as possible or reduce their price to the equilibrium very sluggishly. Therefore, the asymmetric short-run price adjustments do exist if $\left|\theta_j^+\right| > \left|\theta_j^-\right|$. Graphically this means that in Figure 1 the speed at which the short-run price converges to the long-run path would be greater between points (a) and (b) compared to the one located between (b) to (c). There are also 11 dummy variables, DUM_{it}, in equation (3) capturing the month of the year effect.

As stated earlier, the optimum threshold values are not necessarily equal to zero when: $EC_{jt-1} = \hat{\varepsilon}_{jt-1} \Rightarrow p_{jt-1} - (\hat{\alpha}_0 + \hat{\alpha}_1 o_{t-1} + \hat{\alpha}_2 s_{t-1} + \hat{\alpha}_3 T_{t-1}) = 0$

Therefore, on average the optimal threshold value (τ) could then be located: (1) at the intersection points (a) or (b) or (c), where $\tau = 0$; or (2) at a point between (a) and (b) such as (a'), where $\tau < 0$; or (3) at a point between (b) and (c) such as (b'), where $\tau > 0$. Equation (3) can be interpreted as a two-regime vector error-correction model with a single cointegrating vector and an endogenously-determined threshold effect in the error-correction term. This equation allows for an asymmetric adjustment response working not only through the deviation from the long-run path (Hansen and Seo, 2002) but also through positive and negative short-run dynamic effects of the two exogenous variables in the model (i.e. γ_i^+, γ_i^-, η_i^+ and η_i^-). Bachmeier and Griffin (2003); Borenstein, Cameron and Gilbert (1997); Granger and Lee (1989) and Radchenko (2005) suggest this flexible framework to capture any asymmetric effects by alternating regimes as periods of either rising or falling prices associated with each of these possible sources.

It is not counterintuitive to assume that the two explanatory variables to be at least weakly exogenous as their values are highly likely to be determined outside of the vector error correction system: crude oil and the Singapore petrol prices in global petroleum markets and the exchange rate (appearing in the denominator converting $US to Australian currency) in Forex markets around the globe. Thus, while upstream price shocks will affect petrol prices contemporaneously, petrol price shocks may impact on upstream prices after some lags. Our results (not reported in this paper) indicate no simultaneity problem. Using equation (3) and a Wald test, one can then test whether or not the relationship between the price of petrol and each of its determinants is asymmetric. Based on the test results, the short run asymmetric petrol price responses can be tested as follows:

- Changes in crude oil prices can exert asymmetry effects on petrol prices if $H_0^1 : \gamma_i^+ = \gamma_i^- \quad \forall i$ is rejected.
- Changes in the Singapore petrol prices will impact asymmetrically on petrol prices if $H_0^2 : \eta_i^+ = \eta_i^- \quad \forall i$ is rejected.
- The deviation from the long-run path or *EC* will have an asymmetric effect on petrol prices if $H_0^3 : \theta^+ = \theta^-$ is rejected.

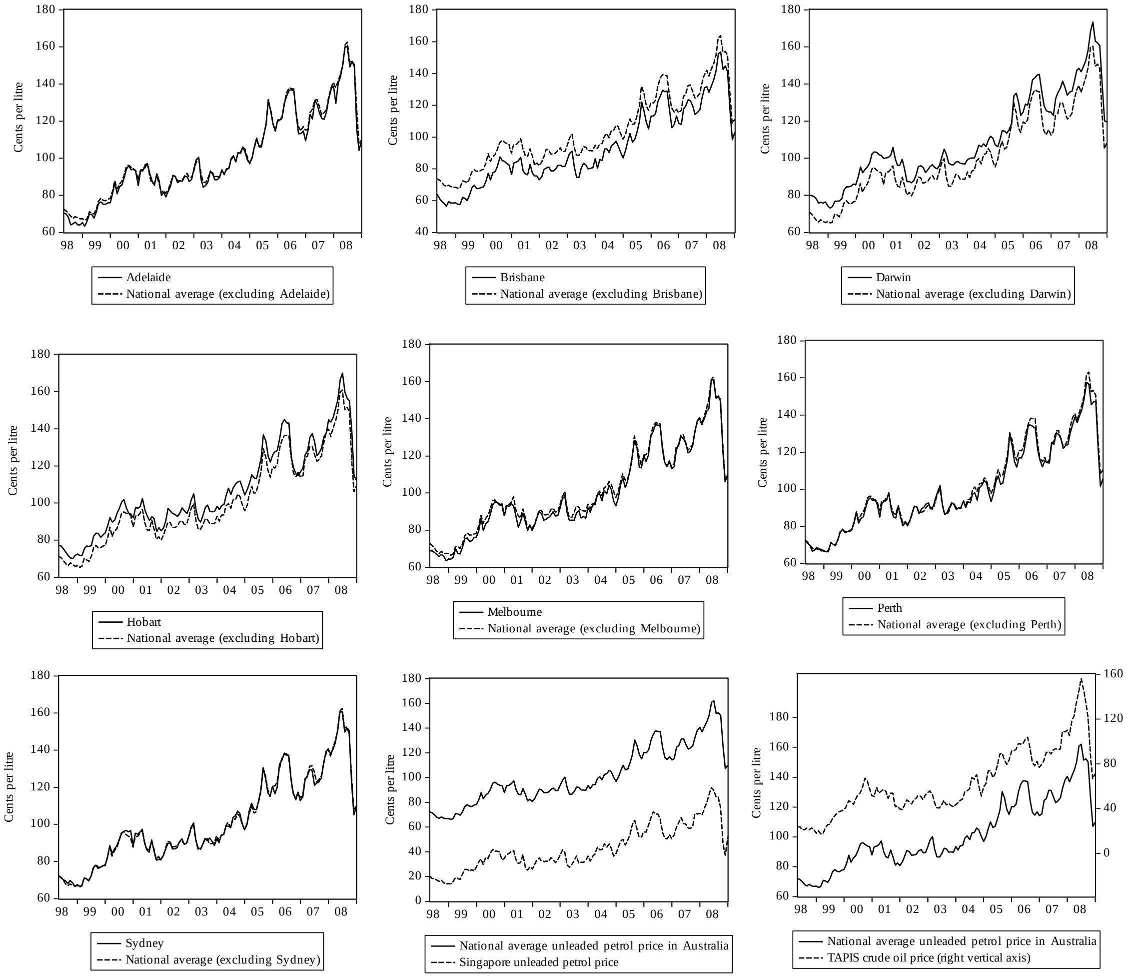
Equation (3) will be estimated for all possible combinations of the values of the lags (ranging between 0-5). The threshold parameter for *EC* appearing on the right hand side of equation (3) will be determined endogenously using a standard grid search. In the grid search for the best threshold value, the minimum value of grid will be incremented by 0.0001 sequentially till the maximum value is reached. To have enough observations in each regime, EC_{jt} are first sorted in ascending order, and based on the middle 70 per cent of the observations, the minimum and maximum gird search values are determined. *Ceteris paribus*, any value of the threshold which yields the lowest residual sum of squares in equation (3) will be considered as a consistent estimate of the threshold. The optimum lag length (k) is chosen on the basis of the AIC. The general-to-specific methodology is used to omit insignificant variables in equation (3) on the basis of a battery of maximum likelihood tests as well as the AIC. In this method, joint zero restrictions are imposed on current and lagged explanatory variables in the unrestricted (general) model to obtain the most parsimonious and robust equation in the estimation process.

3. The Data

Before estimating equations (1) and (3) and report our empirical results, it is important to look at the sources and definitions of the data employed in Table 1. The monthly data cover the period May 1998 to January 2009 for all variables indicated in equation (1) including the price of unleaded petrol for seven capital cities: Adelaide, Brisbane, Darwin, Hobart, Melbourne, Perth and Sydney. All the figures in this paper are in Australian dollar unless otherwise is stated. Over this period, Brisbane (92.8 cents) and Darwin (109.2 cents) witnessed the lowest and the highest average unleaded petrol prices, respectively. Monthly minimum price of petrol varied from 63.3 cents in Adelaide to a maximum of 173.4 cents in Darwin. Based on the coefficient of variation (CV), Brisbane and Darwin had the most and the least volatile petrol prices across Australia. Average monthly price of Tapis crude oil ($63.4 per barrel) over the same period was the most volatile series with the highest coefficient of variation (47.4 per cent). The price of Singapore unleaded petrol was the second most volatile series with the CV of 42.6 per cent, fluctuating from 13.8 to 91.8 cents per litre. The reported skewness, Kurtosis and Jarque-Bera statistics in Table 1 indicate that none of the variables are normally distributed. The results of the ADF test are also presented in Table 1, indicating that all of the variables appearing in equation (1) are I(1).

The plots of the price data have been presented in Figure 2. As can be seen, petrol prices in all seven capital cities of Australia very closely follow the national average price series. While due to state government subsidy in Queensland (i.e. 8.5 cents per litre), petrol prices in Brisbane appear to be slightly below the corresponding national average price throughout the period, the opposite is the case for Darwin and Hobart. The overall average price of petrol also closely tracks the movements of both Tapis crude oil price and the Singapore petrol price. Therefore, one would expect that there would be a significant long-run relationship as formulated in equation 1 for each of the seven capital cities. Table 2 presents the results of the Johansen (1995) cointegration trace test as stated in equation (1). Consistent with the results of the Engle-Granger (1987) test and a visual inspection of the data in Figure 2, these results also clearly indicate that there is one statistically significant cointegrating vector within each capital cities at the 0.05 level. Both the final prediction error and the Akaike Information Criterion (AIC) have consistently point to an optimal lag length of 3 for all cities except in the case of Hobart that this lag is found to be two based on the same two criteria.

Figure 2
Plots of the employed data



Source: See Table 1.

4. Empirical Results

Table 3 presents an OLS estimation of equation (1) for each of the seven capital cities over the period May 1998-January 2009. Based on the last two columns of this table, the resulting residuals from the estimated long-run equations are all I(0) at 1 per cent level of significance, supporting the notion of cointegration according to the Engle and Granger (1987) two step procedure. The adjusted R^2 are all very high ranging from a minimum of 0.959 for Darwin to 0.981 for Adelaide. The estimated cointegrating vectors, capturing the long-run effects of the price of Tapis crude oil (o_t) and the Singapore price of unleaded petrol (s_t) on Australia's petrol prices, are all statistically significant at 1 per cent or better with the expected positive signs. The long-run elasticity of petrol price with respect to o_t across all seven capital cities vary from a minimum of 0.065 in Perth to an unusually high value of 0.146 in Darwin. It should be noted that this elasticity is roughly around 0.07-0.08 mark for all other six capital cities.

Table 1: Sources and definitions of the monthly data employed (May 1998- January 2009).

Variable	Unleaded petrol price (P_{it}) in:							O_t	S_t	E_t
Description	Adelaide	Brisbane	Darwin	Hobart	Melbourne	Perth	Sydney	Tapis crude oil spot price[6]	Singapore unleaded petrol price[6]	Exchange rate
Sources	AAA[1]	AAA[1]	AAA[1]	AAA[1]	AAA[1]	AAA[1]	AAA[1]	EIA[2]	EIA[3]	RBA[5]
Unit	Cents per litre	Cents per litre	Cents per litre	Cents per litre	Cents per litre	Cents per litre	Cents per litre	FOB $A per Barrel	FOB Cents per litre[4]	$US per $A
Mean	100.6	92.8	109.2	106.7	100.1	100.4	101.6	63.4	42.8	0.68
Maximum	160.1	153.4	173.4	170.1	161.4	157.6	160.8	156.1	91.8	0.96
Minimum	63.3	56.4	73.1	70.1	63.4	66.2	66.4	17.4	13.8	0.49
Std. Dev.	23.3	23.7	23.9	23.5	23.7	22.3	23.0	30.0	18.3	0.12
CV	23.2	25.5	21.9	22.0	23.7	22.2	22.6	47.4	42.6	17.6
Skewness	0.536	0.576	0.647	0.618	0.586	0.583	0.588	0.801	0.638	0.35
Kurtosis	2.60	2.50	2.59	2.65	2.55	2.56	2.59	3.33	2.77	2.34
Jarque-Bera	7.04	8.49	9.88	8.87	8.50	8.36	8.34	14.37	9.04	4.9
P-value	0.03	0.01	0.01	0.01	0.01	0.02	0.02	0.00	0.01	0.08
Level form	$Ln(P_1)=p_1$	$Ln(P_2)=p_2$	$Ln(P_3)=p_3$	$Ln(P_4)=p_4$	$Ln(P_5)=p_5$	$Ln(P_6)=p_6$	$Ln(P_7)=p_7$	$Ln(O)=o$	$Ln(S)=s$	$Ln(E)=e$
ADF test	-1.52	-1.59	-1.35	-1.64	-1.62	-1.68	-1.65	-1.81	-1.79	-1.35
P-Value	0.52	0.49	0.61	0.46	0.47	0.44	0.46	0.37	0.39	0.61
Optimum lag	8	3	2	2	2	2	2	2	2	1
First difference	Δp_1	Δp_2	Δp_3	Δp_4	Δp_5	Δp_6	Δp_7	Δo	Δs	Δe
ADF test	-5.14	-7.43	-8.14	-7.37	-8.42	-8.59	-8.43	-9.06	-9.22	-9.78
P-Value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Optimum lag	7	2	1	1	1	1	1	0	1	0

1. Australian Automobile Association: www.aaa.asn.au/issues/petrol.htm
2. Energy Information Administration: http://tonto.eia.doe.gov/dnav/pet/pet_pri_spt_s1_d.htm
3. Energy Information Administration: http://tonto.eia.doe.gov/dnav/pet/hist/rp15sin5d.htm
4. Gallon has been converted to litre assuming 1gallon=3.785 litre
5. Reserve Bank of Australia: http://www.rba.gov.au/Statistics/HistoricalExchangeRates/index.html
6. O_t and S_t were in the US dollars and US cents, respectively but they were converted to the Australian currency using the RBA's exchange rate.

Table 2: Trace cointegration test results.

Hypothesized no. of CE(s) for:	Eigenvalue	Trace Statistic	0.05 Critical Value	P-value**	Optimum lag
Adelaide					3
None	0.315	66.42*	42.92	0.00	
At most 1	0.101	19.20	25.87	0.27	
At most 2	0.046	5.89	12.52	0.47	
Brisbane					3
None	0.319	63.69*	42.92	0.00	
At most 1	0.073	15.76	25.87	0.51	
At most 2	0.049	6.25	12.52	0.43	
Darwin					2
None	0.259	55.22*	42.92	0.00	
At most 1	0.071	17.51	25.87	0.38	
At most 2	0.063	8.17	12.52	0.24	
Hobart					2
None	0.312	67.79*	42.92	0.00	
At most 1	0.098	20.58	25.87	0.20	
At most 2	0.059	7.61	12.52	0.29	
Melbourne					3
None	0.321	64.29*	42.92	0.00	
At most 1	0.073	15.93	25.87	0.50	
At most 2	0.050	6.41	12.52	0.41	
Perth					3
None	0.310	61.88*	42.92	0.00	
At most 1	0.076	15.49	25.87	0.53	
At most 2	0.044	5.63	12.52	0.51	
Sydney					3
None	0.312	64.47*	42.92	0.00	
At most 1	0.085	17.68	25.87	0.37	
At most 2	0.052	6.64	12.52	0.38	

Note: * denotes rejection of the hypothesis at the 0.05 level; and ** denotes the MacKinnon-Haug-Michelis (1999) p-values

Table 3: Long-run determinants of unleaded petrol prices in capital cities of Australia (1998M05-2009M01)

Dependent variable	R^2	$\overline{R}^2$	Identifier	Cointegrating vectors				F-stat.	Residuals ADF *t* ratio	ADF p-value
$Ln(P_{it})$				Intercept	o_t	s_t	T_t			
Adelaide	0.981	0.980	Coefficient	2.574	0.074	0.325	0.001	2095		
			t-ratio	37.7	2.5	9.8	7.9		-5.31	0.00
			p-value	0.00	0.01	0.00	0.00	0.00		
Brisbane	0.980	0.979	Coefficient	2.448	0.073	0.326	0.002	2007		
			t-ratio	32.1	2.2	8.8	10.3		-4.73	0.00
			p-value	0.00	0.03	0.00	0.00			
Darwin	0.959	0.958	Coefficient	3.123	0.146	0.169	0.002	980		
			t-ratio	34.1	3.7	3.8	7.8		-4.53	0.00
			p-value	0.00	0.00	0.00	0.00			
Hob	0.966	0.965	Coefficient	2.915	0.080	0.261	0.002	1184		
			t-ratio	34.5	2.2	6.4	7.7		-4.51	0.00
			p-value	0.00	0.03	0.00	0.00	0.00		
Melbourne	0.976	0.975	Coefficient	2.643	0.084	0.299	0.002	1683		
			t-ratio	34.3	2.5	8.0	8.4		-4.28	0.00
			p-value	0.00	0.01	0.00	0.00			
Perth	0.972	0.972	Coefficient	2.750	0.065	0.295	0.001	1468		
			t-ratio	35.62	1.9	7.9	7.8		-4.15	0.00
			p-value	0.00	0.05	0.00	0.00	0.00		
Sydney	0.974	0.973	Coefficient	2.712	0.087	0.289	0.001	1562		
			t-ratio	35.5	2.6	7.8	7.3		-4.08	0.00
			p-value	0.00	0.01	0.00	0.00	0.00		

The same thing can be said in relation to the long-run elasticity of petrol price with respect to s_t. With the exception of Darwin, the Singapore petrol price elasticity can narrowly vary from a minimum of 0.261 (Hobart) to a maximum of a 0.326 (Brisbane). In the case of Sydney, for instance 10 per cent rise in o_t and s_t will result in 0.87 and 2.89 per cent increase in the price of petrol in the long-run. The time trend variable (T_t) is also highly significant and exerts a positive impact on each dependent variable. Based on these results, one can conclude that as expected both Tapis crude oil and the Singapore unleaded petrol price are the two major long-run determinants of Australian petrol price with the latter exerting a higher impact in terms of the magnitude of its estimated long-run elasticities.

Starting with a maximum lag of five (k=5) in equation (3), the general-to-specific methodology is used to omit the insignificant variables in this equation on the basis of a battery of maximum likelihood tests and the AIC as a model selection criterion. Using I(0) variables in the estimating procedure, joint zero restrictions are imposed on the explanatory variables in the general model or equation (3) to obtain the most parsimonious and robust estimators. The empirical results for the parsimonious models capturing short-run dynamics for unleaded petrol prices in seven capital cities are presented in Table 4. The estimated coefficients of the final specific models are all statistically significant at least at the 10 per cent level or better and have the expected theoretical signs. Despite being in log difference forms, these equations also performs extremely well in terms of goodness-of-fit statistics. The adjusted R^2 varies from a minimum of 0.755 in Darwin to a maximum of 0.848 in Adelaide and the overall F test rejects the corresponding null hypothesis at the one per cent level. Furthermore, the estimated equations pass a battery of diagnostic tests and show no sign of misspecification, except for the Jarque-Bera normality test for Darwin and Hobart. The estimated coefficients have been sensibly signed, with log changes in both Tapis crude oil and the Singapore petrol price having positive short-run elasticities. Furthermore, at least one of the corresponding feedback coefficients $\left(\theta^{+} \text{ and/or } \theta^{-} \text{ or } \theta\right)$ for the EC term is highly significant, validating the significance of the cointegration relationship in the short-run model for petrol price. Based on the estimated short-run dynamic models presented in Table 4, the major findings of the paper have been summarised below.

First, the Singapore price of petrol appears to be a major determinant of petrol prices for each and every capital cities in Australia not only in the long-run (See Table 3) but also in short-run (Table 4). Second, although Tapis crude oil price exerts a long-run influence on Australia's petrol prices (see Table 3), its short-run impacts are confined to only three capital cities namely Brisbane, Darwin and Sydney) occurring with two or three months delay. The log changes of crude oil price did not have any instantaneous effect on changes in petrol prices in any Australia' capital cities. Also the current and lagged values of this variable were not statistically significant for the other four cities and as a result they were not included in the estimated final equations in Table 4. It can thus be concluded that Australia's short-run petrol prices in Adelaide, Hobart, Melbourne and Perth are mainly influenced by the current or lagged (up to three months) changes in the Singapore price of petrol. The short-run variations in the price of petrol in Brisbane, Darwin and Sydney on the other hand are mainly driven not only by the current or lagged (up to two months) changes in the Singapore petrol price but also by the lagged (up to three months) changes in the Tapis crude oil price. Third, in all capital cities (with the only exception being Darwin) the short-run changes in the price of crude oil did not exert any asymmetry effects on the changes in petrol prices as $H_0^1 : \gamma_i^{+} = \gamma_i^{-} \quad \forall i$ was rejected.

Table 4: Asymmetric short-run dynamic models for changes in petrol prices (1998M05-2009M01).

Explanatory variables	Adelaide			Brisbane		
	Coefficient	*t* stat.	P-value	Coefficient	*t* stat.	P-value
Intercept	-0.001391	-0.6	0.5265	-0.005749	-1.8	0.0781
Δo_{t-2}				0.053153	2.1	0.0388
Δo^{-}_{t-2}						
Δo^{-}_{t-3}						
Δs_{t}	0.325082	19	0	0.337	17	0
Δs^{-}_{t}						
Δs^{+}_{t}						
Δs_{t-1}	0.17175	10	0	0.234349	6.2	0
Δs_{t-2}						
Δs^{-}_{t-2}				0.084541	2.4	0.018
Δs^{-}_{t-3}	0.081019	2.6	0.0113			
EC_{jt-1}						
EC^{-}_{jt-1}	-0.350122	-2.7	0.0078	-0.545676	-4.4	0
EC^{+}_{jt-1}	-0.117606	-1.4	0.1536	0.003718	0	0.9662
DUM-January						
DUM-April						
DUM-November				0.014493	2.1	0.0419
DUM-December	0.012381	1.9	0.058	0.017727	2.6	0.0117
Δp_{it-1}				-0.228877	-2.7	0.0069
Asymmetric test on the *EC* term	Statistics		P-Value	Statistics		P-Value
$H_0 : \theta^{+} = \theta^{-}$	**F(1,110)=2.65**		**0.09**	**F(1,116)=10.63**		**0.00**
EC:						
Lower value of grid for the threshold	-0.0299			-0.0332		
upper value of grid for the threshold	0.0367			0.0380		
Optimal value	-0.0204			-0.0177		
R^2	0.858			0.846		
$\bar{R}^2$	0.848			0.834		
F-statistic	85.5		0.00	70.9		0.00
DW	2.02			1.94		
Diagnostic tests						
Jarque-Bera	0.57		0.75	3.76		0.16
Breusch-Godfrey Serial Correlation LM F Test:						
2 lags	1.80		0.17	0.24		0.79
4 lags	1.60		0.18	1.17		0.33
8 lags	1.64		0.14	0.96		0.47
12 lags	1.60		0.18	1.05		0.41
Heteroskedasticity Tests						
Breusch-Pagan-Godfrey F test	1.50		0.19	0.70		0.70
ARCH F test						
1 lag	0.00		1.00	0.05		0.83
2 lags	0.51		0.60	1.11		0.33
4 lags	1.60		0.18	0.92		0.40
White F test						
With cross terms	0.71		0.90	0.85		0.73
Without cross terms	0.85		0.57	0.97		0.47
Ramsey RESET F Test:	2.10		0.32	1.66		0.20

Table 4 (continued): Asymmetric short-run dynamic models for changes in petrol prices.

Explanatory variables	Darwin			Hobart		
	Coefficient	*t* stat.	P-value	Coefficient	*t* stat.	P-value
Intercept	0.0051	2.5	0.01	0.0002	0.1	0.92
Δo_{t-2}						
Δo^{-}_{t-2}	0.0859	2.5	0.01			
Δo^{-}_{t-3}	0.0754	2.2	0.03			
Δs_{t}	0.1782	11.5	0.00	0.1970	11.7	0.00
Δs^{-}_{t}						
Δs^{+}_{t}						
Δs_{t-1}	0.1568	9.7	0.00	0.1932	10.4	0.00
Δs_{t-2}	0.0344	1.9	0.07	0.0489	2.8	0.01
Δs^{-}_{t-2}						
Δs^{-}_{t-3}						
EC_{jt-1}	-0.1178	-2.8	0.01	-0.2053	-4.0	0.00
EC^{-}_{jt-1}						
EC^{+}_{jt-1}						
DUM-January						
DUM-April						
DUM-November						
DUM-December						
Δp_{it-1}						
Asymmetric test on the *EC* term	Statistics		P-Value	Statistics		P-Value
$H_0 : \theta^{+} = \theta^{-}$	F(1,117)=1.57		0.21	F(1,121)=1.41		0.24
EC:						
Lower value of grid for the threshold	-0.0515			-0.0378		
upper value of grid for the threshold	0.0513			0.0446		
Optimal value	0.0512			0.0433		
R^2	0.767			0.773		
$\bar{R}^2$	0.755			0.765		
F-statistic	64.6		0.00	103.8		0.00
DW	2.02			2.09		
Diagnostic tests						
Jarque-Bera	14.12		0.00	19.65		0.00
Breusch-Godfrey Serial Correlation LM F Test:						
2 lags	2.29		0.11	0.42		0.66
4 lags	1.27		0.29	0.40		0.81
8 lags	0.89		0.53	0.33		0.95
12 lags	0.93		0.51	0.43		0.95
Heteroskedasticity Tests						
Breusch-Pagan-Godfrey F test	0.59		0.73	1.53		0.20
ARCH F test						
1 lag	0.05		0.82	0.22		0.64
2 lags	0.09		0.91	0.74		0.48
4 lags	0.52		0.72	0.41		0.80
8 lags	0.36		0.94	0.14		1.00
White F test						
With cross terms	0.65		0.90	0.74		0.73
Without cross terms	1.72		0.12	0.33		0.86
Ramsey RESET F Test:	1.29		0.26	1.11		0.29

Table 4 (continued): Asymmetric short-run dynamic models for changes in petrol prices.

	Melbourne			Perth		
Explanatory variables	Coefficient	*t* stat.	P-value	Coefficient	*t* stat.	P-value
Intercept	-0.000975	-0.4	0.7135	0.0064	2.6	0.01
Δo_{t-2}						
Δo^{-}_{t-2}						
Δo^{-}_{t-3}						
Δs_{t}	0.307729	17	0			
Δs^{-}_{t}				0.3412	13.1	0.00
Δs^{+}_{t}				0.2334	7.0	0.00
Δs_{t-1}	0.156855	8.4	0	0.1713	9.9	0.00
Δs_{t-2}						
Δs^{-}_{t-2}						
Δs^{-}_{t-3}	0.094017	2.9	0.0047			
EC_{jt-1}				-0.1150	-2.3	0.03
EC^{-}_{jt-1}	-0.414065	-4	0.0001			
EC^{+}_{jt-1}	-0.116623	-1.5	0.1326			
DUM-January				-0.0111	-1.7	0.09
DUM-April				-0.0118	-1.7	0.08
DUM-November						
DUM-December	0.016535	2.4	0.0178			
Δp_{it-1}						
Asymmetric test on the *EC* term	Statistics		P-Value	Statistics		P-Value
$H_0 : \theta^{+} = \theta^{-}$	**F(1,118)=4.69**		**0.0324**	F(1,119)=0.77		0.38
EC:						
Lower value of grid for the threshold	-0.0368			-0.0319		
upper value of grid for the threshold	0.0459			0.0423		
Optimal value	-0.0244			-0.0291		
R^2	0.816			0.838		
$\bar{R}^2$	0.807			0.828		
F-statistic	87.4		0.00	88.4		0.00
DW	2.30			2.04		
Diagnostic tests						
Jarque-Bera	2.90		0.23	3.00		0.22
Breusch-Godfrey Serial Correlation LM F Test:						
2 lags	2.26		0.11	0.59		0.56
4 lags	1.89		0.12	0.43		0.79
8 lags	1.20		0.31	0.41		0.91
12 lags	1.06		0.40	0.43		0.95
Heteroskedasticity Tests						
Breusch-Pagan-Godfrey F test	0.53		0.78	0.50		0.81
ARCH F test						
1 lag	0.33		0.57	0.23		0.63
2 lags	0.40		0.67	0.12		0.88
4 lags	0.26		0.90	0.23		0.92
8 lags	0.51		0.85	0.37		0.94
White F test						
With cross terms	0.63		0.91	0.73		0.86
Without cross terms	0.36		0.90	0.58		0.79
Ramsey RESET F Test:	1.29		0.26	0.04		0.85

Table 4 (continued): Asymmetric short-run dynamic models for changes in petrol prices.

Explanatory variables	Sydney		
	Coefficient	*t* stat.	P-value
Intercept	0.0013	0.5	0.65
Δo_{t-2}	0.0379	2.0	0.05
Δo^{-}_{t-2}			
Δo^{-}_{t-3}			
Δs_{t}			
Δs^{-}_{t}	0.3242	12.8	0.00
Δs^{+}_{t}	0.2263	6.9	0.00
Δs_{t-1}	0.1492	8.6	0.00
Δs_{t-2}			
Δs^{-}_{t-2}			
Δs^{-}_{t-3}			
EC_{jt-1}			
EC^{-}_{jt-1}	-0.2596	-2.7	0.01
EC^{+}_{jt-1}	-0.0285	-0.4	0.68
DUM-January			
DUM-April			
DUM-November			
DUM-December			
Δp_{it-1}			
Asymmetric test on the *EC* term	Statistics		P-Value
$H_0 : \theta^{+} = \theta^{-}$	**F(1,119)=3.10**		**0.08**
EC:	ECM7		
Lower value of grid for the threshold	-0.03628		
upper value of grid for the threshold	0.046328		
Optimal value	0.02772		
R^2	0.829		
$\bar{R}^2$	0.819		
F-statistic	82.3		0.00
DW	2.01		
Diagnostic tests			
Jarque-Bera	4.40		0.12
Breusch-Godfrey Serial Correlation LM F Test:			
2 lags	0.13		0.88
4 lags	0.12		0.97
8 lags	0.45		0.89
12 lags	0.41		0.96
Heteroskedasticity Tests			
Breusch-Pagan-Godfrey F test	0.82		0.56
ARCH F test			
1 lag	1.05		0.40
2 lags	1.52		0.22
4 lags	1.20		0.31
8 lags	0.84		0.57
White F test			
With cross terms	0.67		0.92
Without cross terms	0.82		0.58
Ramsey RESET F Test:	1.11		0.29

Fourth, except in Darwin and Hobart that $H_0^2: \eta_i^+ = \eta_i^- \ \forall i$ could not be rejected, this hypothesis was rejected at the 5 per cent level of significance for the other five cities and for some values of i. Therefore, it can be stated that changes in the Singapore petrol prices have asymmetrical impacts on petrol prices in all capital cities except Darwin and Hobart. It is interesting to note that where significant, the estimated coefficient for Δs_{t-i}^- was greater than the corresponding coefficient for Δs_{t-i}^+. So in those capital cities for which $H_0^2: \eta_i^+ = \eta_i^- \ \forall i$ were rejected, on an absolute value basis negative changes in the Singapore price could exert greater impacts on petrol prices compared to the corresponding positive changes of the same magnitude. This means for example 10 per cent decrease in Δs_{t-i}^- will lead to greater changes in Δp_t than a similar 10 per cent increase in Δs_{t-i}^+. This might appear to be quite favourable to consumers in the short-run but the analysis is not complete without undertaking a formal test on the third hypothesis, which is $H_0^3: \theta^+ = \theta^-$.

Fifth, the results in Table 4 indicate that $H_0^3: \theta^+ = \theta^-$ can be rejected at 9 per cent level of significance or better for Adelaide, Brisbane, Melbourne and Sydney, supporting the asymmetric price adjustment hypothesis. For these four cities the estimated θ^- coefficients (in terms of their absolute values) were far greater than their corresponding θ^+ coefficients. This means that according to the past data when the short-run prices are above the long-run path (see equation 2), retail suppliers in these cities on average are more inclined to reduce their price to the equilibrium level very sluggishly. But on the other hand when petrol prices are below the long-run path, retail distributors increase their prices immediately to the equilibrium level. $\left|\theta_j^-\right|$ varies from a minimum of $\left|-0.26\right|$ in Sydney to a maximum of $\left|-0.55\right|$ in Brisbane, suggesting that between 26-55 per cent of the short-run deviation (i.e. under pricing) from the long-run path is eliminated each month. Based on these results if prices were above the long-run path, within 2-4 months that divergence would have disappeared. According to the magnitude of the estimated adjustment coefficients in Brisbane ($\theta_2^- = -0.55$) and Melbourne ($\theta_5^- = -0.41$), petrol price increases are passed on to the consumer faster than price decreases.

However, when the short-run deviations are positive (prices are above the long-run path), the speed of adjustment coefficients are much slower and/or statistically insignificant (see the estimated coefficients of EC_{jt-1}^+ or θ_j^+ for Adelaide, Brisbane, Melbourne and Sydney). Under these circumstances, the short-term variations in prices mainly corrected through variations in Δs_{t-i}^- and/or Δs_{t-i}^+ or Δs_{t-i} and to a lesser extent through the lagged changes in crude oil prices. Therefore, the asymmetric price adjustments do exist for four out of seven Australia's capital cities since $\left|\theta_j^+\right| > \left|\theta_j^-\right|$. As can be seen from the estimated Wald tests in Table 4 no evidence of asymmetric price adjustment was found for Darwin, Hobart and Perth. The estimated *symmetric* speed of adjustment or θ_j are -0.118, -0.205 and -0.115 for Darwin, Hobart and Perth, respectively. Based on absolute values, the speed of adjustment for these three cities is also much lower than $\left|\theta_j^-\right|$ obtained for the other four cities[4].

Sixth, the month-of-the year effects are significant in only four out of seven cities: positive impacts on average petrol price changes in December (Adelaide, Brisbane and Melbourne) and November (Brisbane) and negative impacts on the average price of petrol in Perth in both January and April. There are three possible explanations for the asymmetric response of petrol prices: (a) the

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[4] It should be noted that the optimum threshold values ranged (expressed in natural logarithm) from a minimum of -0.0204 (Adelaide) to a maximum of 0.0512 (Darwin), translating to 0.97 cents and 1.05 cents, respectively. Since the threshold value (τ) is so close to zero (when the dotted and solid graphs intersect each other in Figure 1), the optimum value will be in vicinity of points a, b and c in Figure 1.

oligopolistic price coordination theory (e.g Borenstein, Cameron & Gilbert 1997), (b) the production and inventory cost of adjustment (e.g. Kaufmann & Laskowski, 2005), and (c) the search theory (Johnson, 2002). Based on oligopolistic coordination theory, an increase in the price volatility can lead to a faster response of petrol prices to an oil price decrease and a reduction in the degree of asymmetry in the petrol price response. According to the search theory, an increase in retail price of petrol raises the incentive to search for a lower priced retail outlet, while a decrease in the price lowers the incentive to search. Peltzman (2000) also believes various measures of imperfect competition, inventory cost, inflation-related asymmetric menu costs, and input price volatility determine the degree of such an asymmetry.

5. Concluding Remarks

This paper tests the asymmetric responses of petrol prices at retail level to the positive and negative changes in each of the major sources of petrol price rises which are (1) Tapis crude oil prices; and (2) the Singapore petrol prices. The asymmetric effect of the error-correction term, representing the price deviation from its long-run path, has also been tested in the proposed models. This means that the negative and positive deviations from the long-run equilibrium prices are also allowed to exert asymmetric effects in the short-run error correction model.

It is found that in the long-run petrol prices in Australia are mainly determined by both Tapis crude oil and the Singapore unleaded petrol price, with the latter exerting a higher impact in terms of the magnitude of its estimated long-run elasticities. The results indicate that in the case of a short-run price perturbation, petrol price increases are mostly passed on to the consumer faster than price decreases. In four major capital cities (i.e. Adelaide, Brisbane Melbourne and Sydney), it is found that $\left|\theta_j^-\right| > \left|\theta_j^+\right|$, providing convincing evidence in support of asymmetric price adjustments and the Bacon’s (1991) “rockets-and-feathers hypothesis”. In other word, petrol prices respond quickly following negative deviation from the long-run patch and there would be much slower adjustment speed when petrol prices are above the long-run equilibrium path. One can thus argue that there are a significant degree of market inefficiency and/or collusion or tacit collusion, requiring a closer government price monitoring and scrutiny.

Of course these results are very aggregate and not specific enough to policy formulation. Future research can use more disaggregated data to provide relevant region-specific policy implications. For example, to achieve this, one can purchase daily data for 113 sample retail petrol stations over the same period (1998-2009) across seven states from the Australian Automobile Association. The results of such a disaggregated analysis can then assist relevant government and private agencies (such as the ACCC, the Australian Automobile Association, Australian Institute of Petroleum, FuelWatch and MotorMouth etc.), which can play an important role in market efficiency and consumers’ protection. For instance, motorists can find out in which sample retail outlet and/or geographical areas petrol price increases are passed on to them (if any) faster than price decreases and vice versa. The use of aggregated data can mask the existing price differences in small regional towns and rural areas. However, based on aggregate results this paper finds enough evidence for overall asymmetric price responses, justifying an urgent need for conducting further research and monitoring/regulating the price of petrol set by major oil companies in Australia. The use of more disaggregated data can make the retail and wholesale petrol markets more transparent by rigorously examining and testing the asymmetric petrol price responses arising from all of its possible external sources and providing region-specific recommendations.

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