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Do Petrol Prices Increase Faster than They Fall in Market Disequilibria?

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Abstract

This paper tests the idea that petrol prices respond more quickly to price increases than to decreases. We show that the results previously documented in the literature for Australia are spurious due to failure to establish the stationarity property of the price series, and the co-integration relationship between retail and wholesale prices when neglecting to account for a regime shift in the data. Using a robust approach involving a threshold error correction model, we find little evidence to support the contention that retail petrol price reverts asymmetrically to long-run equilibrium. Asymmetric adjustments in retail prices are found only in four of the twenty-eight retail gas stations in Queensland. These results cast doubt on the previously reported pervasiveness of this asymmetric price response phenomenon in Australia. We further caution on erroneous inference with the use of weekly rather than daily data, and when failing to account for a regime shift in the data.

JEL Classification: C51, Q43, L16

Keywords: Asymmetric responses, petrol prices, Threshold Error Correction model

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1. Introduction

The established literature has argued that gasoline prices respond quickly to crude oil price increases, but adjust more slowly to crude oil price decreases (Bacon, 1991; Borenstein et al., 1997; Bachmeier and Griffin, 2003). This phenomenon has been referred to as *rockets and feathers* for the reason that gasoline prices 'shoot up like rockets' in the face of positive oil price shocks and 'float down like feathers' in response to negative shocks (Bacon, 1991). While the rockets-and-feathers hypothesis has predominantly been examined in the U.S. market, it has been investigated extensively in other non-US markets such as the Spanish fuel market (Balaguer and Ripolles, 2012) and the Australian petrol market (Valadkhani, 2013), just to name two countries by way of example.[1]

Importantly the Australian study differs from the Spanish one in the use of weekly data rather than daily data. Balaguer and Ripolles (2012) highlight the importance of using daily data on the basis that gas stations are able to adjust their prices daily, particularly given that gas stations set their prices according to the rapidly changing conditions in the wholesale fuel market. To that end, daily data would reveal more information about the retail price adjustment process. From an econometric standpoint, inadequate temporal disaggregation could result in the omission of important short time lags, which may introduce significant bias to estimates (Geweke, 1978). An important and well established finding is that estimates from average data per week also suffer from temporal aggregation bias (Bachmeier and Griffin, 2003; Balaguer and Ripolles, 2012). And as we document in our study, this temporal aggregation in weekly price series can give rise to a different stationary property compared with daily price series. An important implication of the difference in results about the mean-reversion behavior of petrol prices is that it hinders the application of the long-run cointegration framework, which is commonly used for testing asymmetry in the retail price adjustments when it deviates from wholesale price. Consequently, there is a need to undertake further research that uses daily retail petrol prices in Australia.

This paper critically evaluates the model used by Valadkhani (2013) in testing the rockets-and-feathers hypothesis for Australia's petrol market. In addition to employing daily

[1] Other country studies include Liu et al. (2010) who examine price asymmetry for diesel and petrol in New Zealand, and Bermingham and O'Brien (2010) who test the rockets-and-feathers hypothesis in the Irish and UK petroleum and diesel markets.

data, which overcomes the temporal aggregation bias that has been documented in previous studies, this paper demonstrates the importance of testing for cointegration relationship between retail and wholesale petrol prices in the presence of a structural break, and the need for a robust model specification which captures important features of the data when testing for asymmetric responses of retail petrol price to wholesale price changes. To this end, we focus our analysis on the state of Queensland (QLD), a state which exhibited significant evidence of rockets-and-feathers behavior in retail petrol prices, apart from Tasmania (TAS) and New South Wales (NSW) (Valadkhani, 2013). QLD also has far more retail locations than TAS or NSW and Australian Capital Territory (ACT) combined.[2] For the purpose of exposition, the general reference to petrol is with regard to unleaded petrol.

Following the literature, Valadkhani (2013) estimates a long-run relationship between retail and wholesale petrol prices for which the resulting residuals from that regression form the error correction term which enters a second stage regression. Prior to running the second regression, he tests for the stationarity property of petrol prices. However, when neglecting to account for a structural break in the data, he erroneously concluded that the series are non-stationary when in fact they are stationary with a regime shift in both intercept and trend. Furthermore, he tested for co-integration between retail and wholesale prices even though the two series are I(0). Unfortunately, he also used a wrong set of critical values based on the Augmented Dickey Fuller critical values rather than the appropriate critical values for cointegration test. The results yield erroneous conclusion about the stationarity property of the residuals obtained from the first stage regression. Be that as it may, Valadkhani continued to assess evidence of asymmetry using the second stage regression. Specifically, he relied on the feedback coefficients, which are associated with the error correction term that is proxied by the residuals. The idea is that these feedback coefficients measure the different speeds of adjustment when deviations from the long-run equilibrium occur. For reasons not explained by Valadkhani (2013), he assumes that the residual (or the error correction term) follows a Gaussian normal distribution. The assumption of normality implies a symmetric distribution which allows him to choose two threshold levels (i.e. 0.44σ and -0.44σ) that divide the distribution into three equal portions. Here, σ denotes the standard deviation of petrol prices. The upper (lower) portion of the distribution is associated with the error correction (or residual) value that is greater (lesser) than or equal to 0.44σ (-0.44σ), which he defined as

[2] TAS has 8 retail locations, NSW and ACT (combined) have 30 while QLD has 28.

EC^+ (EC^-). The test for asymmetry amounts to testing the null hypothesis of equality in the coefficients of EC^+ and EC^- .

This study shows that the use of weekly data employed in Valadkhani (2013) fail to justify the application of a cointegration framework given the stationary property of petrol prices. In contrast, our results show that daily petrol prices exhibit non-stationary property when the regression specification used for testing a unit root properly accounts for a structural break in the data. For the 28 gas stations data examined, we find that only 15 retail prices display a long-run relationship with wholesale prices when a structural break is accounted in the cointegration regression. In addition, we show that the normality assumption imposed by Valadkhani (2013) on the error correction term and the residual of the regressions, are tenuous and that the data fail to support them. The Jarque-Bera test overwhelmingly rejects the null of normality in the resulting regression residuals of the 15 retail prices. A plot of their empirical distributions superimposed on a normal distribution visually suggests that the normality assumption is untenable. Since Valadkhani fails to establish the normality of the residual, there is a flow-on effect on the *ad hoc* determination of the threshold levels, which – contrary to his assertion - fail to demarcate the distribution into three equal portions. Given that the threshold levels are chosen incorrectly the test of the null hypothesis on the equality of the coefficients, which are associated with the different regions of the distribution would be erroneous.

We present a model which better captures certain empirical features of the data compared to the one estimated by Valadkhani (2013). First, we establish that there is a long-run equilibrium relationship between retail and wholesale prices when a structural break is taken into consideration in the cointegration regression. Failure to accommodate a regime shift in the cointegration relationship can result in failure to reject the false null of no cointegration (Gregory and Hansen, 1996), which is corroborated in our findings. The resulting residual from this cointegration regression can be used to determine whether there is asymmetric adjustment in retail prices whenever the market is in disequilibrium. We also relax the assumption of normality in the distribution of the residual. Given the evidence of departure from normality in petrol prices, we use a Student's t-distribution. As we show in the sensitivity analyses, this assumption matters for correct inference. Secondly, there is no *a priori* reason other than for convenience that the threshold levels are chosen so as to divide the error distribution into three equal portions. It is common in the literature to employ zero as the default threshold since positive and negative values can be easily associated with the different speeds of adjustment when the deviation is above or below the long-run equilibrium level.

Rather than fix this threshold at zero, we consider an alternative approach which allows the data to determine the threshold level. This approach is similar to the threshold adjustment which is developed by Enders and Siklos (2001). Their method permits asymmetry in the speed of adjustment towards equilibrium with the threshold level purely determined by the data. Having estimated the model, we test the null of equality in the coefficients which measure the speed of adjustment when the discrepancies are positive and negative from the threshold level. This forms the basis for testing the asymmetric price responses. Thirdly, the volatility specification of retail petrol prices is permitted to respond asymmetrically to the sign and size of the shocks. By appropriately modelling the empirical features in the data, we show that the results fail to support the pervasiveness of rockets-and-feathers behavior in petrol prices in the Queensland state as claimed by Valadkhani (2013). Our results provide new and robust evidence for the lack of asymmetric retail price adjustments, which has been a topic of significant interest by the public due to its implications for consumer welfare.[3] Of the 28 retail stations examined, only four retail petrol prices are found to exhibit asymmetric price adjustments.

The rest of the paper is structured as follows. Section 2 provides a review of the literature. Section 3 discusses the data sources, explains the summary statistics of the data and preliminary results of the cointegration test and the empirical distribution of the resulting residuals. Section 4 presents the model, the procedure for determining the threshold and the test for asymmetric price responses. Section 5 discusses the results. Section 6 concludes the paper with a summary of the main arguments presented here.

2. Literature Survey

2.1 What gives rise to oil price asymmetric adjustments?

Empirical observation of oil price asymmetric response to changes in wholesale prices can be rationalized by oil companies taking advantage of their dominant market power in an

[3] The social concern is based on studies documenting that oil companies have a propensity to take advantage of oil price variations in the international market. Their aim is to increase revenues by failing to adjust retail prices in accordance with movements of the wholesale prices. Consequently, consumers are expected to pay higher prices which reduce their welfare. (Galeotti et al., 2003; Contin Pilart and Correljé, 2009; Balaguer and Ripolles, 2012).

oligopolistic industry (Contín-Pilart and Correljé, 2009). The extent of price asymmetry depends on the number of competitors in the market; fewer competitors are associated with more price asymmetry. Oligopolistic markets exist due to high barriers to entry. Some barriers include the requirement for government licensing and large economies of scale that exist in the fuel market. Collusive behavior is thought to be a common practice in the oligopolistic fuel market where prices are set unfairly higher for consumers. Borenstein et al. (1997) show that tacit collusion is practised by firms in which they use past prices as a focal point to exploit market power. Tacit collusive behavior is an undeclared agreement, where collusion occurs either through excessive advertising or when a market leader sets a benchmark price for competitors to follow. In the event that wholesale prices increase, each retailer is quick to raise prices to signal to their competitors that they are following a tacit agreement. When upstream prices decline, firms are slow to adjust prices since they run the risk of signaling to competitors that they no longer follow a tacit agreement (Galeotti et al., 2002). As a result of collusion, this may lead to delayed price reductions but not price increases.

Another possible explanation for oil price asymmetric adjustments is the break down in collusions amongst retail gas stations. Once retailers adopt a trigger strategy (resulting in temporary increase in market share for a particular firm), the slow gradual decline in retail price will soon lead to a rapid fall in prices to their competitive levels as firms compete for market share. If market power is indeed present and firms temporary practise this asymmetric pricing behavior, the situation is unlikely to last because firms are faced with consumer search costs in search for cheaper prices (Brown and Yücel 2000). As petrol prices change frequently, it is difficult for consumers to maintain accurate price information (Lewis 2011).

Lewis (2011) has developed a reference point search model to illustrate that the amount of effort consumers spend on searching depends on their expectations of what prices should be, which are prices in the previous period. When wholesale prices increase, retailers act to maintain their profits by passing on the increase to consumers who notice that prices are higher than their reference point (i.e. the last period price). Consumers then begin to search for cheaper petrol prices that are in line with their expectations. Increased search effort leads to changes in the price elasticity of demand faced by firms, leading to smaller profit margins at each station, thus forcing prices to fall to their competitive levels. Alternatively, when retail prices begin to decline as a result of falling wholesale prices, consumers will search less because the price is either equal to or less than their reference point. Hence, the natural tendency is that consumers are willing to pay the first price they notice and do not search as much. This leads to a slower reduction in retail price which makes the market less competitive and firms experience higher margins in the short-term (Brewer et al., 2014).

According to Brown and Yücel (2000), beyond market power and search costs, there are other explanations for the asymmetric price response of petroleum. Consumer responses to changes in petrol price can contribute to asymmetric price responses. Suppose there is a sudden depletion of crude oil or the Australian exchange rate is expected to depreciate (which was the case during the Global Financial Crisis in 2008), consumer demand for petrol would accelerate and induce further increases in rising prices. Retailers would experience temporary shortages in current inventories and be forced to increase prices rapidly to account for excess demand. As Brown and Yücel (2000) explained, firms may face adjustment costs, if oil supply is reduced; wholesalers have little choice but to reduce output quickly, which would lead to a rapid increase in retail prices. On the contrary, when crude oil supplies are increased, suppliers would not have to increase output quickly. They could delay price reduction by controlling the outflow of petroleum products, which could lead to delays in price reduction.

2.2 Empirical evidence of oil price asymmetric adjustments

Empirical results on petrol price asymmetry are mixed. Past studies have differed in terms of the variables examined, sample period used, the frequency of the data, estimation techniques employed and the country under scrutiny. The lack of a unifying framework for testing and examining petrol price asymmetry has led to the ongoing debate and development of novel modelling and testing approach in the literature. The pioneering work on analyzing price asymmetry is the study by Bacon (1991), which examines the United Kingdom's fuel market using data from 1982 to 1989. Bacon discovers that retail prices appeared to rise faster to increases in the price of crude oil compared to when prices decline. Bacon (1991) was the first to coin the term "rockets and feathers" where prices rise like *"rockets"* and fall like "*feathers"* when changes occurred to the upstream supply of petrol.

In another influential paper by Borenstein et al. (1997) who extensively study the distribution process for fuel in the United States, the authors analyze price transmission at different points in the distribution, such as crude oil-retail and wholesale-retail margins. They find an asymmetric relationship exists between wholesale and retail margins. In particular, they find that crude oil retail asymmetry prices depend on a number of factors like the transporters, wholesale margins, and exchange rates, amongst others.

In a related study, Radchenko (2005) examines the link between oil price volatility and asymmetry responses of gasoline prices to oil prices increases and decreases in the United States. He finds that the degree of asymmetry in gasoline prices declines with an increase in oil price volatility, which is consistent with the prediction offered by the oligopolistic coordination theory. Brewer et al. (2014) argue that many retailers prefer volatility in upstream prices. Specifically, when firms experience low profits at times of increasing wholesale costs, price cycles with higher price volatility had economically significant benefits especially when prices decline as retailers are able to make large short-term profits.

For a state-specific study, Verlinda (2008) explores asymmetrical relationships in petrol prices in the state of California. The influence of geographical and product differentiation has shown that petrol prices rise faster for wholesale price increases than they fall for decreases in cost. It is found that local-market differentiation is associated with higher asymmetry than those without differing characteristics (brand of product), which would lead to potential market power. The results suggest that differentiated products offered to consumers wielded an influence on the degree of price asymmetry.

Not all empirical studies which test the rockets-and-feathers phenomenon support this hypothesis. An early study conducted by Karrenbrock (1991) provides an example for the effects of wholesale price changes onto retailers using a distributed lag model. Karrenbrock finds that the lag effects are symmetric for leaded petrol using monthly data. Bachmeier and Griffin (2003) extend the work of Borenstein et al. (1997) by using both weekly and daily data for the U.S. market. The authors find evidence of asymmetry for the weekly series between crude oil and wholesale price deviations, however, when employing daily data, Bachmeier and Griffin (2003) find no evidence of asymmetry for the margins.

More recently, Bermingham and O'Brien (2010) have empirically tested whether the Irish and UK petroleum and diesel markets are subjected to asymmetric pricing. Employing a Threshold Autoregressive model (TAR) with monthly data, they find evidence to support the rockets-and-feathers hypothesis. On the other hand, Liu et al. (2010) examine the diesel and petrol industry in New Zealand, and they fail to find any evidence of price asymmetry between crude oil and wholesale prices for petroleum. Nevertheless, there is statistical evidence of diesel prices responding asymmetrically to price increases and decreases. They rationalized that diesel prices are not as competitive as petrol because they are mainly used in the business sector of New Zealand, and to that end oil companies take advantage of the relatively inelastic demand for diesel by users.

A survey of the literature on asymmetric fuel price responses to price increases or decreases is extensive and it is not possible to include all of them in this section. Nonetheless, our survey of the literature highlights a number of critical issues that need to be addressed when assessing the rockets-and-feathers hypothesis. Fundamentally, the econometric model needs to be sufficiently flexible to capture empirical features of the data. Alongside the model, equally important is the data frequency that is employed to empirically test the hypothesis. It appears that the use of a disaggregated dataset (i.e. daily) is preferred by many researchers since it captures better variation in oil price movements (Polemis and Fotis, 2013). However, in many cases daily data can be difficult to obtain due to data unavailability. In this paper, we take issue with these two fundamental issues of data frequency and model specification to demonstrate that they matter for the assessment of the rockets-and-feathers hypothesis.

3. Data and Summary Statistics

3.1 The Data

The dataset is purchased from Fueltrac (www.fueltrac.com.au) and specifically focuses on the state of Queensland, Australia for the period from 29 October 2007 to 30 April 2014, which comprises 2377 daily observations.[4] Daily data are obtained given that retailers are able to adjust their prices daily. Additionally, using a more disaggregated data like daily data would permit a closer examination of the price variation and reveal information about the behavior of retailers, which would otherwise be masked when using weekly or monthly data as is commonly reported in most studies. In total there are 28 retail and 5 wholesale locations in the Queensland dataset.

There are two prices of interest, namely retail prices and terminal gate prices (TGP) or wholesale prices. Terminal gate prices (TGP) are the spot prices where fuel can be purchased by retailers located close to the wholesale distributor. Petroleum either comes from domestic

[4] The source of the dataset is similar to the one used by Valadkhani (2013). However, Valadkhani employs weekly data and for a shorter period from 29 October 2007 to 30 January 2012.

refineries or is imported from international port terminals. There are two price benchmarks that are important in determining the terminal gate prices (TGP). They are the import parity prices (IPP) and wholesale prices (ACCC Monitoring of the Australian Petroleum Industry 2014, p.61). The IPP is the cost of importing refined petrol where this index is used as a margin for determining domestic wholesale prices. The IPP plays a central role in determining prices where movements in this index can have a major influence on the downstream supply chain. Given that Singapore is the major source of imported fuel which makes up approximately 40% of the Australian market, Singapore's wholesale prices are closely followed as a benchmark to determine domestic prices. In sum, terminal gate prices can be decomposed into the following constituents:

$$Terminal\ Gate\ Price = IPP + tax(including\ GST) + operational\ costs + profit$$

-Figure 1 about here-

In Australia, except for Western Australia, retailers are free to adjust prices on a daily basis. Changes to daily retail prices are influenced by international prices for fuel, the Australian exchange rate, taxes and variations in wholesale and retail margins. Dispersions in retail prices can vary substantially between regional and metropolitan areas. Retailers who operate further away from their wholesale distributors such as regional retailers are on average expected to offer a higher pump price in comparison to city retailers. One reason for this is that regional retail stations only experience fuel deliveries every two to three weeks in comparison to city stations, which usually take delivery every week since retailers operating in metropolitan areas experience a higher quantity demand for petroleum than those in regional areas. Furthermore, distance travelled by delivery trucks also has an influence on the retail cost margins when determining the daily pump price. Generally, the further away a service station operates from its nearest wholesale distributor the higher are the freight costs which are transferred onto the final price. Changes in the production and wholesale margins for petrol tend to have the highest influence on the price offered by retailers. In summary, it can be seen in Figure 1 that the average national price of petrol for 2012-2013 is made up of the refined production cost accounting for 56% of retail price, followed by government taxes which account for 36% of retail price. The remainder consists of wholesale and retail cost margin.

-Figures 2 and 3 about here-

Evidence of daily seasonality is present in the data and hence a seven-day moving average is applied to remove the influence of seasonal patterns. Plots of the movement of retail and wholesale prices are depicted in Figures 2 and 3, respectively. Figure 2 shows the retail prices in Queensland from 28 retailers. The colored lines represent the prices offered by retailers across the state. It can be seen that at any point in time, the variation in petrol price offered by retailers is substantive. These price differences can be attributed to retailers' geographical or location differences. In contrast, the 5 terminal gate prices illustrated in Figure 3 show no signs of large price dispersions from each other. This is not surprising given that the majority of the wholesale distributors operate close to the shoreline. Figure 4 shows a map of Queensland in which the retail locations denoted by green triangles were matched with their closest wholesale supplier and distributors marked by red diamonds, namely Brisbane, Cairns, Gladstone, Mackay and Townsville. It is evident that all wholesale suppliers are located along the shoreline. The graphs for retail and terminal gate prices show that these prices are somewhat moving in tandem suggesting that a cointegration relationship could exist between them. Furthermore, there is a large fall in petrol prices around about 2008, which may suggest the presence of a structural break that would need to be accounted for when undertaking both the unit root and cointegration tests.

-Figure 4 about here-

3.2 Data Summary Statistics

Tables 1 presents the summary statistics for retail and wholesale locations, respectively, from 4/11/2007 to 30/4/2014. Based on the average retail prices, five of the most expensive locations are Cloncurry ($1.55), Charleville ($1.48), Cunnamulla ($1.48) Longreach ($1.47), and Mt. Isa ($1.45). On the other hand, the least expensive retail locations were Brisbane ($1.36), Caloundra ($1.36), Ipswich ($1.36), Toowoomba ($1.33) and Warwick ($1.36). These price differences should not come as a surprise since retailers that offer higher prices tend to be located in regional Queensland compared to cheaper locations operating closer to their nearest wholesale distributors. Differences in the average price offered by petrol stations can also be a result of different economies of scale arising from population density, travel distance and competition.

-Tables 1 about here-

The kurtosis for the distribution of petrol prices in 28 locations is less than zero, suggesting that the distribution is broader, flatter, and has thinner tails than a Gaussian normal distribution. Many of the statistics are statistically different from zero, which is the value of the kurtosis for a normal distribution. Moreover, all of the distributions are negatively skewed implying that the distribution is non-symmetric. Given the evidence of skewness and non-normal kurtosis, the Jarque Bera test statistic for the null of normal distribution is comfortably rejected at the 1% level of significance for all retail and wholesale prices in all locations.

We also undertake unit root test and cointegration tests with and without structural breaks. Results of the unit root Augmented Dickey Fuller (ADF) test without structural breaks are not reported here for brevity, but they are available from the authors upon request. To endogenously determine the break when testing for stationarity, we use the Zivot and Andrews (1992) test (ZA test, henceforth). Table 2 shows the results of the ZA test and as anticipated allowing structural breaks in the intercept gives rise to a break that coincides with the suspected break in September 2008. However, in all cases, we fail to reject the unit-root in favor of stationarity with one break for wholesale and retail prices in all locations.

-Tables 2 and 3 about here-

Since both retail and wholesale prices are non-stationary, and the fact that both price series are seen to move together closely (see Figures 1 and 2), we test for a cointegration long-run relationship by accommodating a structural break. The test for cointegration is performed between a retail price and its closest wholesale price using both the Engle and Granger (1987) (EG, henceforth) procedure and the Gregory and Hansen (1996a) (GH, henceforth) procedure, which accommodates a structural break. The shift in intercept, the trend term and the slope coefficient are permitted in the model specification with a structural break. For an exposition of the cointegration regression with a structural break in practice, the reader is referred to Gregory and Hansen (1996b). Table 3 reports the results for the cointegration analysis among the pair of retail and wholesale prices for both EG and GH procedures. Gregory and Hansen (1996b) utilize the method of Mackinnon (1991) to calculate the approximate asymptotic critical values for regime shift in the cointegration relationship. Appropriate lags were chosen for the specification based on minimizing the Akaike Information Criterion (AIC). The EG test statistic rejects the null hypothesis of no cointegration in 5 of the 28 locations (i.e. Brisbane, Caboolture, Caloundra, Gold Coast and Ipswich) in favor of the alternative hypothesis that the series are cointegrated. For the GH test statistic, only 15 of the 28 locations show evidence of cointegration between the retail and wholesale prices. Given that cointegration exists only in these 15 retail locations, our empirical assessment of the rockets-and-feathers hypothesis is restricted to these retail prices. Although the precise timing of the breaks varies, the breaks are identified to occur around mid-2008, which coincides with the global recession.[5] These results also demonstrate that failing to account for a structural break can lead to over-rejection of the null of no cointegration, leading to spurious findings of cointegration between retail and wholesale petrol prices.

-Table 4 about here-

At this point it is worth comparing our results with that of Valadkhani (2013). In his study, Valadkhani started his analysis on the premise that the retail price and wholesale price series are cointegrated, and he tested for evidence of cointegration by performing a unit root test on the resulting residuals from the regression. A drawback in his approach lies with the use of the Augmented Dickey Fuller (ADF) critical values to test the null hypothesis that the residuals are non-stationary (i.e. there is no cointegration between retail and wholesale prices).[6] The ADF critical values are not valid given that the residuals are themselves estimates. Appropriate critical values would need to be obtained from simulation. Engle and Granger (1987) report the critical values under the null that the residuals are non-stationary. Mackinnon (1991) provide the approximate asymptotic critical values for the Engle and Granger (1987) test using a procedure which involves fitting a response surface. Table 4 reports the results of the cointegration test done by Valadkhani using weekly prices.

It is apparent from these results which are based on the Dickey-Fuller critical values, sixteen retail prices are cointegrated with the terminal gate prices at conventional levels of significance. However, when the correct critical values are used, only two retail prices are shown to be cointegrated with the terminal gate prices at the 10% significance level. One implication of Valadkhani's results is that if the residuals are shown to be non-stationary as

[5] The global financial recession caused demand for energy to shrink in late 2008, with oil prices collapsing from the July 2008 high of $147 to a December 2008 low of $32.
[6] The ADF critical values for the 1%, 5% and 10% significance level are -3.46, -2.88 and -2.57, respectively (see Table 3 of Valadkhani (2013)). These are simulated critical values obtained for a sample size of 250 observations for a regression that includes a constant but no trend.

evidenced by the use of the appropriate critical values, then it makes little sense to include the residuals from the cointegration regression in the second stage regression. In particular, given that the regression is spurious, inference about the asymmetric adjustment in retail prices when there are disequilibria in the market is in doubt. Clearly, a re-assessment of the rockets-and-feathers hypothesis in the Queensland state is warranted. Further, Valadkhani (2013) fail to perform a cointegration test with structural break(s), implying that his cointegration test results may be biased not only by the use of wrong critical values but also as a result of model misspecification.

4. The Empirical Model

Having established the presence of a cointegration relationship between the price of unleaded petrol prices and its cost, we estimate the following regression:

$$P_{jt} = \beta_{0j} + \beta_{1j}T + \beta_{2j}PW_{it} + \beta_{3j}D_j + \beta_{4j}D_jT + \beta_{5j}D_jPW_{it} + e_{jt} \qquad (1)$$

where (P_{jt}) is the retail price and (PW_{it}) is the wholesale prices at time *t* at the ith location for i=1,…,5, and jth location for j=1,..,28. The time trend variable *T* captures the average increases in related costs associated with the distribution of petrol like transport, insurance and storage (Bacon, 1991). The intercept denotes the level of existing costs for a particular location j. Here, D_j is a dummy variable which equals one from the date when a structural break occurs to the end of the sample period and zero for the period prior to the break. The unobserved error term (e_{jt}) represents the exogenous shocks in the model, which displays the deviations from the long run equilibrium. Moreover, this residual term is essential for analyzing the presence of asymmetric adjustment when there are petrol price increases and decreases which cause retail price to deviate from the wholesale price. Both retail and wholesale prices are expressed in Australian cents per litre. For brevity, we do not report the regression results but they are available from the author upon request.

The short-run dynamic which takes into account possible asymmetric price adjustments can be determined by estimating the following Threshold Error Correction (TEC) model. The second stage regression is:

$$\Delta P_{jt} = \xi_{0j} + \sum_{i=1}^{k} \gamma_{ij}\Delta P_{jt-i} + \sum_{i=0}^{k} \lambda_{ij}\Delta PW_{dt-i} + \sum_{i=1}^{q} \eta_{ij}u_{jt-1} + \rho_{1j}EC_{jt-1}^{\geq\tau_j} + \rho_{2j}EC_{jt-1}^{<\tau_j} + u_{jt}. \qquad (2)$$

Here, ΔP_{jt} measures the first difference of the *j-th* retail location price. The first difference of terminal gate prices are given by ΔPW_{dt-i}. To ensure that the residual v_{jt} is purged of any serial correlation, we fit an ARMA(k,q) model. The EC_{jt-1} measures the error correction term which is given by the one period lagged valued of the residuals obtained in regression (1) for the *j-th* retail location. The threshold value which is determined by the data is denoted by τ_j for the *j-th* retail location. The notation $\geq \tau_j$ ($< \tau_j$) which appears as a superscript in the error correction term denotes the value of the residuals which is larger than or equal to (lower than) the threshold value. The coefficients of interest which capture the asymmetric price adjustment to price increases and decreases are ρ_{1j} and ρ_{2j}, respectively. In general, the value of τ_j is unknown and needs to be estimated along with the values of ρ_{1j} and ρ_{2j}. However, in the literature on testing for asymmetric price adjustment, it seems natural to set $\tau_j = 0$ so that the cointegrating vector coincides with the attractor. In such circumstances, the adjustment is $\rho_{1j}EC_{jt-1}^{\geq\tau_j}$ if the lagged residual value is above the long-run equilibrium and $\rho_{2j}EC_{jt-1}^{<\tau_j}$ if the lagged residual value is below the long-run equilibrium. Failure to reject the null of equality in the magnitude of these two point estimates (i.e. $\rho_{1j} = \rho_{2j}$) would imply that there is no asymmetric price adjustment in petrol prices.

While setting $\tau_j = 0$ may seem a natural and convenient approach when testing for price asymmetry, there is no a priori reason to expect the threshold to coincide with the attractor. When estimating the unknown τ_j, Chan (1993) demonstrated that searching over the potential threshold values so as to minimize the sum of squared errors from the fitted model yields a superconsistent estimate of the threshold. To employ Chan's methodology, the estimated residual series resulting from regression (1) was sorted in ascending order such that $\mathrm{e}_{\mathrm{j}1} < \mathrm{e}_{\mathrm{j}2} < \cdots < \mathrm{e}_{\mathrm{jT}}$ where T denotes the number of usable observations. The largest and smallest 15% of the $\{\mathrm{e}_{\mathrm{jt}}\}$ values were discarded and each of the remaining 70% of the values were considered possible thresholds. For each of these possible thresholds, we estimated an equation in the form of (2). The estimated threshold yielding the lowest residual sum of squares was deemed to be the appropriate estimate of the threshold. Inference concerning the individual values of ρ_{1j} and ρ_{2j}, and the restrictions $\rho_{1j} = \rho_{2j}$ is problematic when the true value of the threshold τ_j is unknown. The property of asymptotic multivariate normality has not been established for this case. In discussing the difficulty of establishing the distribution of the parameter estimates, Chang and Tong (1989) conjectured that utilizing a consistent estimate should establish the asymptotic normality of the coefficients.

Note that our approach differs from Valadkhani (2013) in two important ways. Firstly, we do not make any assumption about the normality in the residuals. In fact, we assume that u_{jt} follows a Student's t distribution. Secondly, the thresholds are not pre-determined by dividing the distribution into three different regions, which are separated by -0.44σ_j and 0.44σ_j. As we have documented in the data and summary statistics section, these pre-determined threshold values do not divide the distribution into three equal portions since the distribution departs from normality and there is evidence of skewness and kurtosis in the distribution.

Thirdly and finally, it is possible that the price series may exhibit autoregressive conditional heteroscedasticity (ARCH) effects (Balaguer and Ripolles, 2012). We model the conditional variance of u_{jt} in equation (2) as a generalized autoregressive conditional heteroscedasticity (GARCH (1,1)) model:

$$h_{jt} = \delta_{0j} + \delta_{1j}\varepsilon_{jt-1}^2 + \delta_{2j}h_{jt-1} \tag{3}$$

To accommodate the potential larger impact of negative shocks on return conditional variance, which is usually termed the asymmetric leverage volatility effect, we also estimate the GJR model developed by Glosten et al. (1993):

$$h_{jt} = \delta_{0j} + \delta_{1j}\varepsilon_{jt-1}^2 + \delta_{2j}h_{jt-1} + \delta_{3j}\varepsilon_{jt-1}^2\, I(\varepsilon_{jt-1} < 0) \tag{4}$$

where $I(\varepsilon_{jt-1} < 0)$ is a dummy variable which takes the value 1 if the shock is negative and zero otherwise. Here, a negative unit shock elicits a larger response in the conditional variance by $(\delta_{1j} + \delta_{3j})$ compared to only δ_{1j} for a positive unit shock. Wei et al. (2010) demonstrate that oil price volatility displays asymmetric volatility.

5. Empirical Results

5.1 Empirical features of the cointegration regression residuals

Figure 5 depicts the plot of the residuals obtained from the cointegration regression. A cursory look at this plot suggests that the empirical distributions of these residuals are not normal. For this reason, the assumption made by Valadkhani (2013) that -0.44σ_j and 0.44σ_j would divide the distribution equally into three portions is in doubt. Equally, the different underlying empirical distribution of the residuals would suggest that the threshold value τ_j would differ from one retail station to the next. For this reason, it is important to estimate the threshold value from the data.

-Figure 5 and Table 5 about here-

Table 5 reports the summary statistics of the residuals from the cointegration regression. It can be seen that by and large the residuals are negatively skewed and the kurtosis ranges from 2 to 4. More importantly, the Jarque-Bera test overwhelmingly rejects the null of normality in all cases thus confirming our suspicion about the departure from normality in the regression residuals as shown in Figure 5. An important implication of these results is that the approach taken by Valadkhani (2013) who assumes that the residuals are normally distributed and the use of an *ad hoc* approach to divide the supposed normal distribution into three equal portions, cannot be justified.

5.2 How prevalent is the asymmetric response in petrol prices in Queensland?

Table 6 reports the coefficient estimates of the threshold error correction model given by equation (2). The estimate for ρ_{1j} denotes the adjustment coefficient when the difference between the retail price and the wholesale price is larger than or equal to τ_j, while the estimate for ρ_{2j} denotes the adjustment coefficient when the difference between the retail price and the wholesale price is smaller than τ_j. By and large these values are statistically significant and different from zero, except in some instances such as Cairns and Charter Towers for ρ_{1j} and Cairns for ρ_{2j} for which they are not statistically different from zero. Another interesting observation is that the magnitude of the $|\hat{\rho}_{1j}|$ tends to be larger than $|\hat{\rho}_{2j}|$ in 8 out of 15 cases, which implies that the speed of adjustment is more rapid for positive than for negative discrepancies from $\hat{\tau}_j$. When we test the null hypothesis that $\rho_{1j} = \rho_{2j}$, of the eight cases where we found $|\hat{\rho}_{1j}|>|\hat{\rho}_{2j}|$, only in six retail stations, namely Brisbane metro, Bundaberg, Caboolture, Caloundra, Gold Coast, and Ipswich do we reject the null at the 5% significance level. Taken together, the results suggest that in these six retail stations we fail to find support for the assertion that petrol prices fall more slowly during price increases and increase faster during price decreases. With respect to the other two retail stations which were found to exhibit $|\hat{\rho}_{1j}|>|\hat{\rho}_{2j}|$, the test for the null hypothesis of $\rho_{1j} = \rho_{2j}$ does not find support that there are statistically significant differences in the speed of adjustments for positive and negative discrepancies from $\hat{\tau}_j$.

Finally, referring to the other seven retail stations which display $|\hat{\rho}_{1j}|<|\hat{\rho}_{2j}|$ in the petrol price adjustments, the test for the null hypothesis of $\rho_{1j} = \rho_{2j}$ is rejected for Dalby, Hervey Bay, Toowoomba and Warwick.[7] In other words, for the state of Queensland we find that the evidence for asymmetric response of retail prices in the rate of adjustment toward long-run equilibrium is less prevalent than was previously reported by Valadkhani (2013). Of the 28 stations examined in this study, only 4 retail stations present evidence of asymmetric price responses to petrol price increases and decreases.

-Table 6 about here-

The threshold estimate τ_j varies significantly from station to station. To ensure that these threshold levels are comparable, we standardize them by dividing the threshold estimate with its standard deviation. The standardized threshold is denoted by τ_j^*. It can be seen from these estimates that the assumption of a zero threshold is untenable except in the case of Gladstone which indicates that $\tau_j^* = 0.0075$. The value of τ_j^* tends to be different from 0 and it varies from -1.01 in Dalby to 1.18 in North Coast.

The degree of freedom estimate, v, also varies substantially with the highest value registering for Gladstone (5.182) and the lowest for Brisbane metro, Caloundra and Gold Coast (2.000). This parameter estimate is statistically significant in all cases implying that the assumption of a Student's t distribution is well supported by the data. The low estimate of v with most estimates reporting a value of around 2 implies that the distribution has a lower peak than a normal distribution otherwise would have. In the next subsection we describe the implication of adopting a normal distribution on inference about the asymmetric price adjustments.

There is no pervasive evidence of asymmetric volatility in petrol price returns. Referring to the coefficient estimate of δ_{3j}, the only case when δ_{3j} estimate is statistically significant at the 1% and 5% level is for Hervey Bay and Cairns, respectively. Petrol price return volatility

[7] Although Charter Towers rejects the null hypothesis of $\rho_{1j} = \rho_{2j}$, the value of ρ_{1j} is not different from zero implying that when there is positive discrepancies from $\hat{\tau}_j$ there is no adjustment towards long-run equilibrium.

documents asymmetry at the 10% level for Caloundra and Toowoomba. This would imply that a GARCH(1,1) model may be adequate in modelling return volatility for most of the other retailer petrol prices.

5.3 Sensitivity analyses

(a) Weekly data

To determine the degree by which our results would differ with the use of weekly data, we calculate the weekly average of the daily data. Preliminary analysis of the series using the Zivot-Andrews test suggests that there exists a structural break around about October or November of 2008. And when this regime shift is accounted for in the intercept and trend of the regression, the resulting test statistic overwhelmingly rejects the null of stationarity in favour of a stationary series with a regime shift. Table 7 shows the results of the Zivot-Andrews test which support this conclusion. One important implication of these results is that we cannot proceed to test for asymmetric adjustments in retail petrol prices using the long-run cointegration framework. More importantly, our results for Queensland point to possible erroneous inference which Valadkhani (2013) obtained by using standard unit root tests which fail to account for a structural break. In fact, a cursory look at the data plots for both unleaded petrol prices and terminal gate prices (see Figure 3 and 4, respectively on pp.73 of Valadkahni, 2013) show that there is a visible structural break around about October and November of 2008. These results cast doubt on the evidence of asymmetric petrol price adjustments reported in Valadkhani (2013) study.

-Table 7 about here-

(b) The assumption of a Normal distribution

We estimate the threshold error correction model with the assumption of a Gaussian normal distribution and symmetric volatility. The results which are reported in Table 8 Panel A suggest that there is no evidence of asymmetric price adjustment toward long-run equilibrium that is consistent with the rockets-and-feathers hypothesis. Although we observe that the estimate of ρ_{1j} is smaller in magnitude than ρ_{2j} for the case of Bundaberg, Gladstone and Townsville, and that the null hypothesis of $\rho_{1j} = \rho_{2j}$ is rejected in all the three cases, it is noteworthy that the parameter estimates $\hat{\rho}_{1j}$ and $\hat{\rho}_{2j}$ are not statistically significant and different from zero in some instances. The contrast in results compared with the model which assumes a Student's t distribution is stark, but more importantly, they suggest that failing to specify an appropriate underlying distribution of the data generating process can lead to erroneous inference.

-Table 8 about here-

(c) Daily data and neglecting a regime shift in the cointegration regression

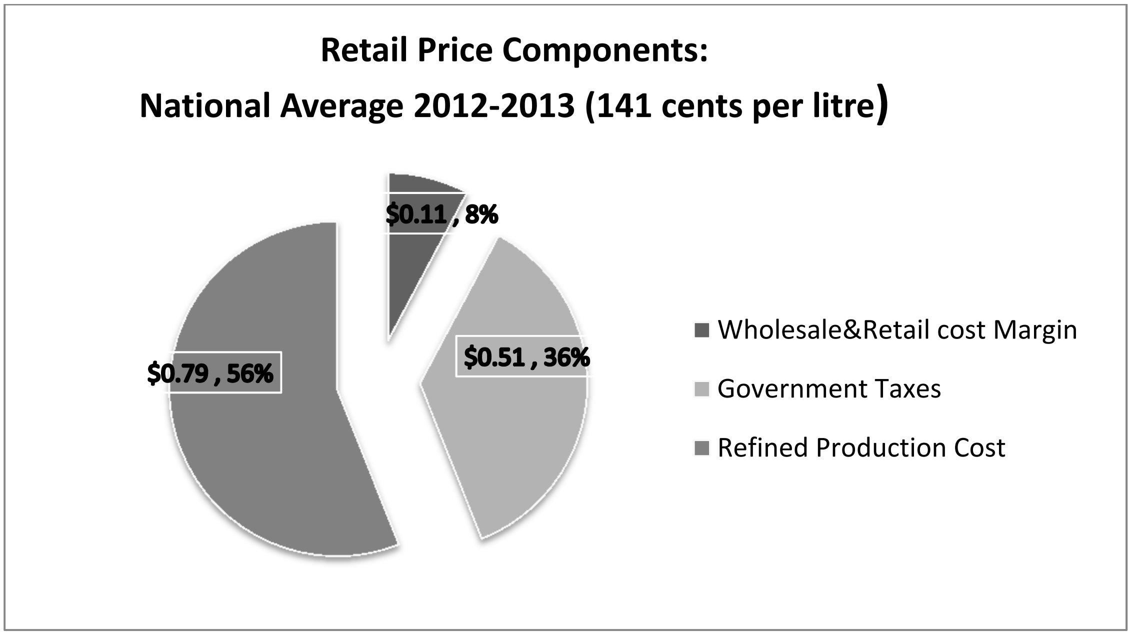
An important consideration in our evaluation of the asymmetric adjustment in retail petrol price towards the wholesale price is the presence of a structural break in the cointegration relationship. We undertake the empirical analysis by deliberately failing to account for a regime shift in the cointegration relationship between petrol retail and wholesale prices. For brevity, we report the estimation results of the threshold error correction model which pertain to the coefficients ρ_{1j} and ρ_{1j}, and the results for the test for the null hypothesis $\rho_{1j} = \rho_{2j}$ (see Table 8, Panel B). It can be seen that there are only two instances when $|\rho_{1j}| < |\rho_{2j}|$, that is for Hervey Bay and Toowoomba. However, the null hypothesis $\rho_{1j} = \rho_{2j}$ is rejected at the 5% significance level only for Toowoomba. Taken together, the results underreport the number of cases which exhibits asymmetric adjustment in petrol prices. Our results suggest the importance of correctly identifying the presence of structural breaks in the data when undertaking an evaluation of the asymmetric price adjustment in petrol prices.

6. Conclusion

The empirical study conducted in this paper is motivated by concerns over the negative effect on consumer welfare when petrol prices remain high despite falling wholesale prices. The pervasiveness of the rockets-and-feathers phenomenon in Australia was brought to light by Valadkhani (2013) who finds that more than a third of the retail gas stations in Queensland exhibit asymmetric price revision towards long run equilibrium when there are market disequilibria. We revisit the empirical framework he employed to determine his findings. We take issue with a number of untenable assumptions and the failure to establish a cointegration relationship between retail petrol price and the wholesale price while accommodating a regime shift in that relationship, which lead to the finding of a disproportionately large percentage of retail gas stations displaying the rockets-and-feathers phenomenon.

Our contributions lie in developing a robust and at the same time more general model which demonstrates that the asymmetric price revision does not have to be governed by a threshold level that is set to zero. In fact, our estimation results indicate that the threshold level which underpins the difference in the price revision arising from positive and negative discrepancies from the threshold level is different from zero. Through a more general and robust characterization of the behavior of petrol prices which allows for a structural break, our results suggest that daily petrol prices adjust asymmetrically to terminal gate price changes only in 4 of the 28 retail gas stations. It is therefore implied that the rockets-and-feathers phenomenon in Queensland is not as pervasive as previously reported. Our results also caution on possible biases in inference when failing to appropriately account for certain empirical features of the data such as neglecting a structural break in the unit root test and the cointegration specification, misspecification of the underlying distribution and using weekly data which are subjected to temporal aggregation bias.

Figure 1 National Average of Retail Price in Australia



Source: Australian Institute of Petroleum National Average 2012

Figure 2 Deseasonalized Retail Prices of 28 Petrol Stations in Queensland

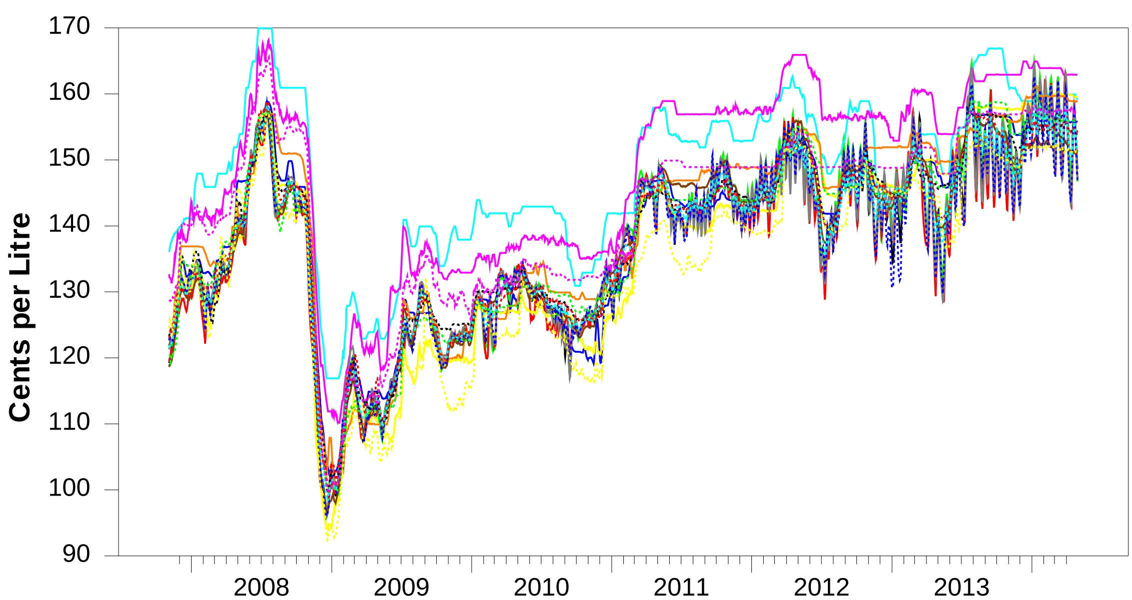


Figure 3 Deseasonalized Terminal Gate Prices of 5 Wholesale Distributors in Queensland

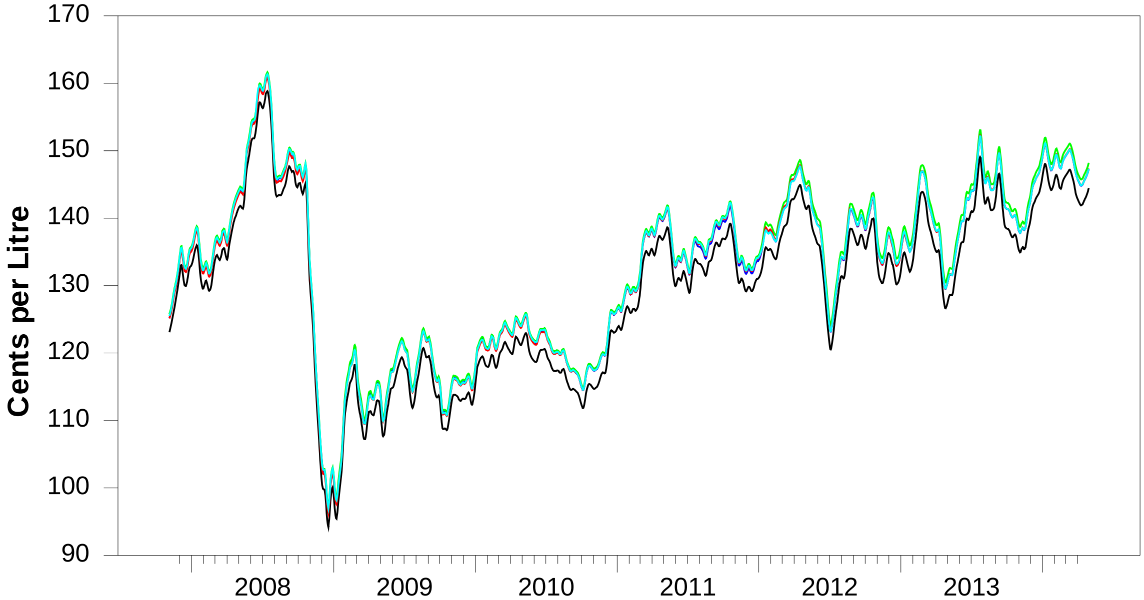
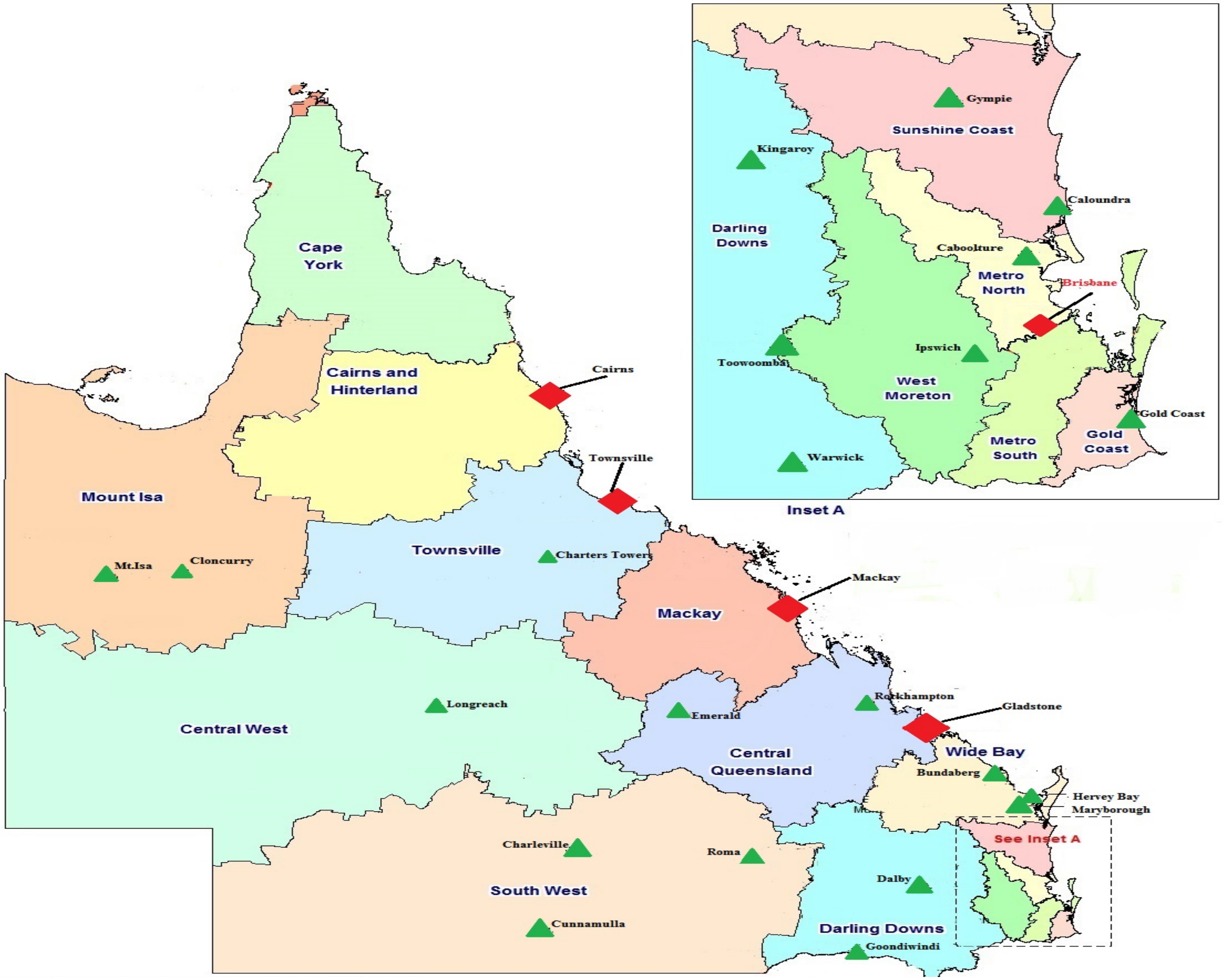
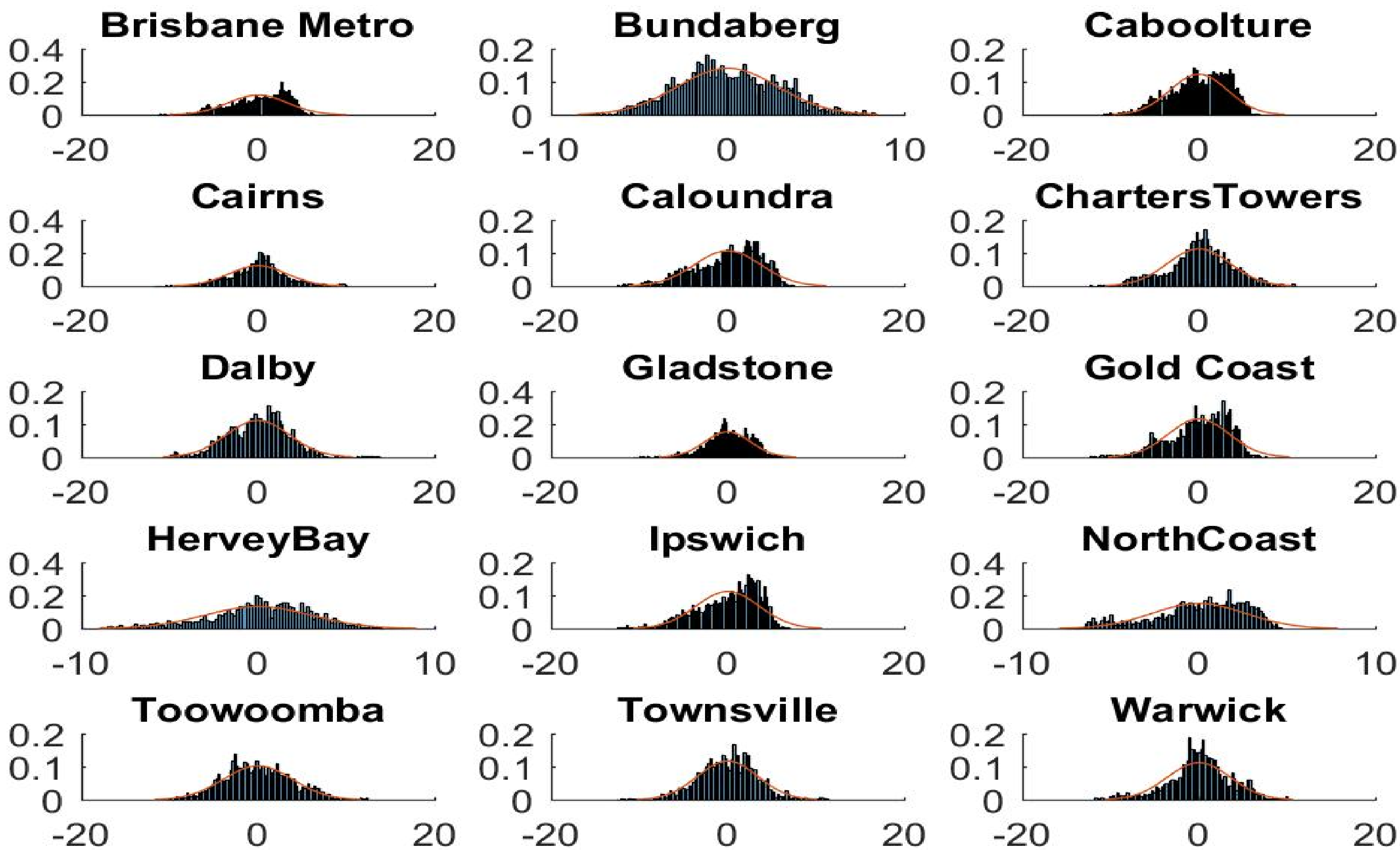


Figure 4 Map of Queensland with Wholesale Distributors and Retail Locations



Note: The red diamonds denote the approximate locations of the wholesale distributors while the green triangles denote the location of the cities or towns associated with various petrol retailers.

Figure 5 Empirical Distribution of the Cointegration Regression Residuals



Note: The solid line which is superimposed on the histogram is the normal distribution with a mean of zero and a standard deviation that corresponds to the standard deviation of the residuals.

Table 1 Descriptive Statistics for 5 Wholesale Prices and 28 Retail Prices

Wholesale Location	Mean (cents per litre)	Standard dev	Skewness	Kurtosis	Jarque-Bera
Brisbane	129.71	12.44	-0.33***	-0.45	62.99***
Cairns	132.48	12.56	-0.34***	-0.49***	70.61***
Gladstone	132.38	12.50	-0.33***	-0.48***	66.72***
Mackay	132.99	12.66	-0.35***	-0.53***	74.90***
Townsville	132.33	12.58	-0.36***	-0.48***	74.42***
Retail Location	**Mean (cents per litre)**	**Standard dev**	**Skewness**	**Kurtosis**	**Jarque-Bera**
Brisbane	136.96	13.64	-0.56***	-0.14	128.21***
Bundaberg	138.36	13.60	-0.48***	-0.72***	144.97***
Caboolture	137.40	13.82	-0.54***	-0.21**	121.02***
Cairns	139.86	14.77	-0.65***	-0.29***	174.64***
Caloundra	136.43	13.55	-0.56***	-0.11	122.91***
Charleville	148.23	11.89	-0.56***	-0.22**	130.47***
Charters Towers	141.75	13.23	-0.80***	-0.07	253.46***
Cloncurry	155.04	15.12	-0.68***	-0.40***	197.49***
Cunnamulla	148.08	13.90	-0.65***	-0.57***	198.64***
Dalby	137.10	15.63	-0.50***	-0.52***	124.92***
Emerald	140.66	14.12	-0.75***	-0.27***	227.51***
Gladstone	139.51	13.27	-0.55***	-0.13	121.65***
Gold Coast	137.17	13.29	-0.57***	-0.07	128.41***
Goondiwindi	140.10	14.66	-0.71***	-0.43***	217.01***
Gympie	137.58	13.85	-0.73***	-0.15	214.88***
Hervey Bay	138.28	13.10	-0.64***	-0.23**	167.34***
Ipswich	136.85	13.32	-0.61***	-0.07	145.27***
Kingaroy	138.18	14.03	-0.62***	-0.28	158.38***
Longreach	147.27	14.34	-0.61***	-0.43***	159.18***
Maryborough	138.04	13.01	-0.60***	-0.31***	153.71***
Mackay	137.75	14.45	-0.69***	-0.22**	193.88***
Mt. Isa	145.28	14.08	-0.57***	-0.58***	163.54***
North Coast	137.36	13.15	-0.67***	-0.13	177.51***
Rockhampton	141.51	13.62	-0.71***	-0.09	198.20***
Roma	142.14	13.50	-0.93***	0.44***	361.77***
Toowoomba	133.93	14.51	-0.67***	-0.32***	185.17***
Townsville	137.33	14.56	-0.74***	-0.03	218.29***
Warwick	136.60	13.64	-0.82***	0.17*	270.95***

Note: *, ** and *** indicate that the null hypothesis that the skewness and kurtosis are equal to zero is rejected at the 10%, 5% and 1% significance level. For the Jarque Bera test, the null hypothesis is that the price series is normally distributed.

Table 2   Zivot-Andrews Test Results for Daily Data

Wholesale Locations	***Break date***	***Test Statistic***	***k* (lags)**
Brisbane	2008:09:11	-2.31	4
Cairns	2008:09:13	-2.29	4
Gladstone	2008:09:13	-2.28	4
Mackay	2008:09:13	-2.34	4
Townsville	2008:09:13	-2.31	4
Retail Locations			
Brisbane	2008:09:13	-2.46	4
Bundaberg	2008:09:30	-2.52	4
Caboolture	2008:09:15	-2.65	4
Cairns	2008:09:16	-2.91	3
Caloundra	2008:09:05	-2.99	4
Charleville	2008:09:26	-1.72	4
Charters Towers	2008:09:22	-2.80	3
Cloncurry	2008:10:01	-2.59	4
Cunnamulla	2008:09:27	-2.46	4
Dalby	2008:09:22	-2.96	4
Emerald	2008:09:24	-2.88	4
Gladstone	2008:09:29	-2.62	4
Gold Coast	2008:09:12	-2.58	4
Goondiwindi	2008:10:01	-2.63	4
Gympie	2008:09:03	-3.45	4
Hervey Bay	2008:09:18	-2.41	3
Ipswich	2008:09:15	-2.44	4
Kingaroy	2008:09:30	-2.96	2
Longreach	2008:09:19	-2.84	1
Maryborough	2008:09:08	-2.88	3
Mackay	2008:10:05	-2.26	4
Mt Isa	2008:09:06	-2.83	3
North Coast	2008:08:30	-3.64	2
Rockhampton	2008:09:30	-2.37	4
Roma	2008:09:23	-3.25	3
Toowoomba	2008:09:26	-2.70	4
Townsville	2008:09:23	-2.55	4
Warwick	2008:09:03	-3.09	4

Note: The critical values for ZA test with a break in the intercept are -5.57 and -5.08 at the 1% and 5% significance levels, respectively. *k* denotes the number of lags in the regression specification which is determined according to the AIC. *, ** and *** indicate that the null hypothesis of a unit root is rejected at the 10%, 5% and 1% levels of significance.

Table 3 Cointegration Test Results With and Without a Structural Break

	Engle-Granger Test	Gregory-Hansen Test		
Locations	**t-statistic**	**t-statistic**	**Break date**	**k**
BRISBANE				
Brisbane	5.30***	-8.31***	2008:06:11	1
Bundaberg	-2.46	-6.07***	2008:10:23	1
Caboolture	-5.15***	-8.50***	2008:02:07	1
Caloundra	-5.09***	-8.57***	2008:07:10	2
Charleville	-1.68	-4.53	2008:07:06	3
Cunnamulla	-1.72	-4.73	2008:11:02	4
Dalby	-2.09	-5.69**	2008:06:14	2
Gold Coast	-5.27***	-8.97***	2008:05:06	1
Goondiwindi	-1.61	-4.27	2008:07:10	4
Gympie	-1.62	-5.40	2008:09:01	3
Hervey Bay	-1.91	-5.95**	2008:05:15	1
Ipswich	-5.02***	-8.60***	2008:07:21	1
Kingaroy	-1.78	-5.48	2008:10:21	3
Maryborough	-2.30	-5.17	2008:11:05	3
North Coast	-2.92	-6.19***	2008:04:03	1
Roma	-1.79	-4.72	2008:06:08	2
Toowoomba	-2.29	-5.55**	2008:04:02	1
Warwick	-1.93	-7.08***	2008:07:08	2
CAIRNS				
Cairns	-1.89	-5.53**	2008:09:26	1
GLADSTONE				
Emerald	-1.74	-4.85	2008:03:21	2
Gladstone	-2.03	-5.74**	2008:11:11	2
Longreach	-1.73	-4.79	2008:05:16	
Rockhampton	-1.85	-5.09	2008:11:04	2
MACKAY				
Mackay	-2.12	-4.85	2008:04:02	2
TOWNSVILLE				
Charters Towers	-2.22	-5.62**	2008:10:30	3
Cloncurry	-2.10	-5.02	2008:10:25	3
Mt. Isa	-2.59	-5.89	2008:10:25	3
Townsville	-2.24	-5.89**	2008:10:18	2

Note: All retailers are paired with the closest wholesaler, which is marked in bold. The critical values for the EG test at the 1, 5 and 10% significance levels are -4.70,-4.14,-3.85 , respectively. The critical values for the GH test at the 1, 5 and 10% significance levels are -6.45,-5.96,-5.72, respectively. The GH critical values are asymptotic approximation calculated by Gregory and Hansen (1996b). *k* signifies the number of lags as determined by the AIC. The locations marked in uppercase refer to the terminal locations.

Table 4 The Cointegration Test Results Reported in Valadkhani (2013)

Locations	t-statistic ADF	t-statistic EG	ADF Critical Value	EG Critical Value
Brisbane Metro	-3.14**	-3.14	-3.46 (1%)	-4.70 (1%)
Bundaberg	-2.46	-2.46	-2.88 (5%)	-4.14 (5%)
Caboolture	-2.83*	-2.83	-2.57 (10%)	-3.85 (10%)
Caloundra	-2.34	-2.34		
Cairns	-2.80*	-2.80		
Charters Towers	-2.45	-2.45		
Cunnamulla	-3.79***	-3.79		
Dalby	-3.21**	-3.21		
Emerald	-2.88*	-2.88		
Gladstone	-2.24	-2.24		
Gold Coast	-3.06**	-3.06		
Goondiwindi	-4.11***	-4.11*		
Gympie	-2.15	-2.15		
Hervey Bay	-2.43	-2.43		
Ipswich	-2.85*	-2.85		
Kingaroy	-2.01	-2.01		
Longreach	-2.74*	-2.74		
Mackay	-4.02***	-4.02*		
Maryborough	-1.96	-1.96		
Mt. Isa	-2.98**	-2.98		
North Coast	-2.72*	-2.72		
Rockhampton	-2.78*	-2.78		
Roma	-2.82*	-2.82		
Toowoomba	-2.04	-2.04		
Warwick	-3.37**	-3.37		

Note: The t-statistic values and the ADF critical values are obtained from Table 3 of Valadkhani (2013). The Engle and Granger (EG) critical values are obtained from Mackinnon (1991, Table 1) corrected critical values for the case with two variables, a constant and a trend. *, ** and *** denote significance at the 10%, 5% and 1% levels, respectively.

Table 5 Summary Statistics of Cointegration Regression Residuals

Retailer location	Terminal location	Kurtosis	Skewness	Jarque-Bera Test
Brisbane Metro	Brisbane	2.6593	-0.6245	164.737***
Bundaberg	Brisbane	2.6593	-0.6245	19.854***
Caboolture	Brisbane	2.6677	-0.5093	112.824***
Caloundra	Brisbane	2.9451	-0.6702	177.032***
Dalby	Brisbane	3.8495	0.0642	72.437***
Gold Coast	Brisbane	3.0695	-0.6935	189.707***
Hervey Bay	Brisbane	3.1912	-0.5449	120.131***
Ipswich	Brisbane	3.1255	-0.7804	241.016***
North Coast	Brisbane	3.3190	-0.5665	179.065***
Toowoomba	Brisbane	2.8760	0.2247	21.331***
Warwick	Brisbane	3.6371	-0.3538	88.952***
Cairns	Cairns	3.7209	-0.0028	51.035***
Gladstone	Gladstone	3.8385	-0.6395	229.525***
Charters Towers	Townsville	3.2558	-0.2705	35.136***
Townsville	Townsville	3.7343	-0.0471	53.783***

Note: See note to Table 1.

Table 6 Coefficient Estimates of the Threshold Error Correction Model with Student's t Distribution

Retailer location	Terminal location	δ_{0j}	δ_{1j}	δ_{2j}	δ_{3j}	ξ_{0j}	$\sum\gamma_{kj}$	$\sum\lambda_{kj}$	ρ_{1j}	ρ_{2j}	η_{1j}	η_{2j}	v	τ_j	τ_j^*	$\rho_{1j}=\rho_{2j}$	k
Brisbane Metro	Brisbane	0.0089***	0.2140***	0.7358***	0.0057	-0.0113***	0.9054***	0.0651	-0.0064***	-0.0037***	0.9358***	-1.1434***	2.0001***	1.1748	0.3497	5.1375**	4
Bundaberg	Brisbane	0.0002**	0.2031***	0.5893***	0.0128	0.0002	0.6349***	0.0149***	0.0005***	0.0003***	0.9995***	1.8010***	2.1006***	3.0607	1.0801	18.0560***	6
Caboolture	Brisbane	0.0229***	0.0976***	0.6251***	0.0348	-0.0125***	0.8767***	0.0801	-0.0102***	-0.0066***	0.9378***	-1.1595***	2.4331***	-2.0984	-0.6451	6.0926**	4
Caloundra	Brisbane	0.0286***	0.0461***	0.6183***	0.0630*	-0.0099**	0.8649**	0.0958	-0.0100***	-0.0033**	0.8800***	-1.0819***	2.0001***	2.4422	0.6527	15.6280***	6
Dalby	Brisbane	0.0001**	0.2185***	0.6935***	0.0345	-0.0002**	0.3311***	0.0402***	-0.0034***	-0.0041***	0.9989***	0.4480***	3.3542***	-3.6278	-1.0121	13.4158***	5
Gold Coast Qld	Brisbane	0.0144***	0.1210***	0.7013***	0.0345	-0.0085***	0.8886***	0.0683	-0.0111***	-0.0047***	0.9465***	-1.1388***	2.0001***	1.2309	0.3577	16.6056***	4
Hervey Bay	Brisbane	0.0001***	0.1786***	0.7742***	0.0706***	0.0061	0.4987***	0.1341***	-0.0020*	-0.0034***	0.9905***	1.7925***	3.9613***	-1.0367	-0.3447	6.1801**	5
Ipswich	Brisbane	0.0271***	0.1073***	0.7255***	0.0971	-0.0053	0.8337	0.0899	-0.0150***	-0.0031**	0.8998***	-1.1182***	2.4895***	-0.5452	-0.1528	20.0788***	5
North Coast Qld	Brisbane	0.0071***	0.1415***	0.5364***	0.0063	-0.0094***	0.8585***	0.0805**	-0.0049***	-0.0034***	0.9610***	-1.1982***	2.4703***	3.1302	1.1854	3.7785*	6
Toowoomba	Brisbane	0.0007**	0.2942***	0.5674***	0.1139*	-0.0016	0.8708***	0.0267	-0.0010**	-0.0020***	0.9960***	-1.2476***	3.2386***	-1.6644	-0.4263	4.4542**	5
Warwick Qld	Brisbane	0.0001*	0.1881***	0.7352***	0.0098	0.0018	0.8901***	0.0326	-0.0008**	-0.0014***	0.9884***	-1.2355***	4.2507***	3.8712	1.0870	6.3941**	4
Cairns	Cairns	0.0003**	0.3019***	0.5338***	0.0764**	0.0009	0.6198***	0.0026	-0.0003	0.0004	0.9872***	0.4377***	2.1359***	-0.9128	-0.2818	3.7443*	5
Gladstone	Gladstone	0.0002***	0.1242***	0.8007***	0.0049	0.0000	0.8339***	0.0444	-0.0015*	-0.0036***	0.9292***	-1.1857***	5.1822***	0.0194	0.0075	2.0169	6
Charters Towers	Townsville	0.0001*	0.1714***	0.7080***	0.0088	-0.0002	0.6812***	0.0046	-0.0003	-0.0026***	0.9643***	-1.2168***	2.7132***	0.6752	0.1905	7.8667***	4
Townsville	Townsville	0.0001***	0.2341***	0.6458***	-0.0153	-0.0014	0.6327***	0.0582***	-0.0026***	-0.0019**	0.9846***	1.7869***	3.1701***	0.8372	0.2451	0.9711	6

Note: *, ** and *** denote significance level at 10%, 5% and 1%, respectively. The parameter estimates correspond to the coefficient estimates in equations (2) and (4). k denotes the lag length of the autoregressive terms which are the first difference of retail prices and the first difference of wholesale prices. τ_j^* denotes the standardized threshold value which is obtained by dividing the threshold value τ_j with its standard deviation. $\rho_{1j} = \rho_{2j}$ is the test for the null that there is equality in the speed of adjustment governing the price revision towards long-run equilibrium. v is the degree of freedom associated with the Student's t distribution.

Table 7 Zivot-Andrews Test for Weekly Data

Wholesale Locations	***Break date***	***Test Statistic***	***k* (lags)**
Brisbane	2008:10:26	-8.25***	3
Cairns	2008:10:26	-8.23***	3
Gladstone	2008:10:26	-8.29***	3
Mackay	2008:10:26	-8.27***	3
Townsville	2008:10:26	-8.19***	3
Retail Locations			
Brisbane	2008:10:26	-6.13***	3
Bundaberg	2008:11:02	-6.57***	4
Caboolture	2008:10:26	-6.16***	3
Cairns	2008:10:26	-7.49***	3
Caloundra	2008:10:26	-5.83***	3
Charleville	2008:10:05	-6.68***	3
Charters Towers	2008:10:05	-6.68***	3
Cloncurry	2008:11:02	-6.30***	2
Cunnamulla	2008:11:02	-5.92***	4
Dalby	2008:11:02	-7.71***	1
Emerald	2008:11:02	-7.42***	3
Gladstone	2008:10:26	-7.44***	1
Gold Coast	2008:11:02	-6.14***	3
Goondiwindi	2008:10:26	-6.48***	2
Gympie	2008:11:02	-6.11***	3
Hervey Bay	2008:11:02	-6.79***	2
Ipswich	2008:11:02	-5.97***	3
Kingaroy	2008:11:02	-6.68***	3
Longreach	2008:10:26	-7.29***	3
Maryborough	2008:10:19	-7.08***	3
Mackay	2008:11:02	-6.72***	2
Mt Isa	2008:10:26	-6.67***	4
North Coast	2008:10:26	-6.41***	3
Rockhampton	2008:10:26	-7.36***	3
Roma	2008:10:26	-7.11***	2
Toowoomba	2008:10:26	-7.27***	3
Townsville	2008:10:19	-6.50***	2
Warwick	2008:10:26	-6.75***	4

Note: The critical values for ZA test with a break in the intercept are -5.57 and -5.08 at the 1% and 5% significance levels, respectively. *k* denotes the number of lags in the regression specification which is determined according to the AIC. *, ** and *** indicate that the null hypothesis of a unit root is rejected at the 10%, 5% and 1% levels of significance.

Table 8 Results of Sensitivity Analyses

		Panel A: Normal distribution with a structural break			Panel B: Daily data without a structural break		
Retailer location	**Terminal location**	ρ_{1j}	ρ_{2j}	$\rho_{1j} = \rho_{2j}$	ρ_{1j}	ρ_{2j}	$\rho_{1j} = \rho_{2j}$
Brisbane Metro	Brisbane	-0.0001	-0.0002	0.0804	-0.0060***	-0.0040***	4.3115*
Bundaberg	Brisbane	-0.0019**	-0.0022	11.0072***	-0.0003***	-0.0003***	9.3840***
Caboolture	Brisbane	0.0000	-0.0005	6.1577**	-0.0253***	-0.0136***	0.0013
Caloundra	Brisbane	-0.0222***	-0.0139***	16.7631***	-0.0103***	-0.0022	17.0262***
Dalby	Brisbane	-0.0070	-0.0061	7.8746***	-0.0018	-0.0027**	12.2815***
Gold Coast	Brisbane	-0.0351	-0.0282	3.0075*	-0.0100***	-0.0051***	11.5490***
Hervey Bay	Brisbane	-0.0123	-0.0036	21.5329***	-0.0047***	-0.0061***	6.6151*
Ipswich	Brisbane	-0.0144	-0.0118	2.4068	-0.0122***	-0.0062***	17.4379***
North Coast	Brisbane	-0.0281***	-0.0078*	13.9388***	-0.0053***	-0.0029***	4.4507*
Toowoomba	Brisbane	-0.0028	-0.0026	0.1112	-0.0012***	-0.0027***	17.5223***
Warwick	Brisbane	-0.7470***	-0.0011	7.8879***	-0.0018***	0.0002	12.4601***
Cairns	Cairns	-0.0027	-0.0009	10.0408***	0.0000	-0.0005**	7.0024***
Gladstone	Gladstone	-0.0015	-0.0057***	7.9323***	-0.0040***	-0.0030***	1.9260
Charters	Townsville	-0.0065	-0.0116*	7.8746***	-0.0011***	-0.0012	0.3983
Townsville	Townsville	-0.0024	-0.0082*	12.7471***	-0.0034***	-0.0026***	6.5285*

Note: *, ** and *** denote significance level at 10%, 5% and 1%, respectively. $\rho_{1j} = \rho_{2j}$ is the test for the null that there is equality in the speed of adjustment governing the price revision towards long-run equilibrium.

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