The Rockets and Feathers Effect: Asymmetric Price Adjustment in the Western Australian Gasoline Market

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Abstract

This study investigates the asymmetric response of gasoline prices to changes in input costs, otherwise known as the rockets and feathers' hypothesis, using a rich dataset from Western Australia. Using daily data, I estimate a multi-stage error correction model and find evidence of asymmetry in the long-run adjustment process for the crude oil to pay-at-pump and wholesale to pay-at-pump relationships. However, no significant evidence of the rockets and feathers effect is found in the short-term dynamics. One interesting aspect of the Western Australia market is that the firms adopt a uniform price cycle within the sample. I show that changes in pricing patterns and market conduct can impact the long-run relationship in downstream gasoline markets, which may –in turn– affect the estimates obtained from traditional error correction models using aggregated data.

J.E.L. Codes: E3, L16, L71, Q4
Key Words: Rockets and Feathers, Error Correction Model, Price Adjustment

1. Introduction

There is a large body of literature dedicated to investigating the dynamic relationship between crude oil and retail gasoline prices. Of particular interest is the asymmetry of price pass-through in gasoline markets: a positive shock to input costs is often associated with a swift increase in retail gasoline prices while the response to a negative shock typically has a longer adjustment period and a lesser magnitude. This asymmetry, deemed the rockets and feathers effect (Bacon (1991), Karenbrock (1991)), has broad implications for a variety of topics from price stickiness and business cycle models to tacit collusion and market power. Indeed, as disaggregated data for gasoline prices became more widely available, many researchers tested for price asymmetry using different samples, econometric methods, and time periods. Despite the breadth of studies, however, results are mixed and not all markets display significant evidence of asymmetric price pass-through.

Recently, Deltas and Polemis (2020) provide a thorough analysis of how estimates may differ depending on research design or features of the data. More specifically, they find that pass-through rates depend on sampling frequency, sample length, temporal aggregation, and market power. Understanding how these characteristics affect traditional results is vital for comparing across the literature as well as for policy analysis. In this paper, I test for asymmetric price pass-through and offer an additional explanation as to why results may differ across studies: uniformly adopted price cycles and tacit collusion may interact with asymmetric pass-through rates.

Understanding how the levels of asymmetry in price adjustment vary across market characteristics is important when considering the role of price stickiness in macroeconomics. Many business cycle models include the assumption of infrequent price adjustments to generate the short-run non-neutrality of money, but explanations for this price stickiness vary across studies. Similarly, price stickiness tends to be a key ingredient in DSGE models that aim to explain the transmission of monetary, fiscal, productivity and technology shocks. As such, investigating key factors that affect asymmetric price pass-through may shed light on the different mechanism that lead to infrequent price adjustments and, thus, inform modeling choices in the theoretical literature on the transmission of shocks.

At the same time, if firms respond slower to decreases in input cost shocks compared to equivalent increases, they could be seen as using their market power to increase profit. This behavior is of natural interest to anti-monopoly government agencies when investigating potential collusion within a geographic market. While many gasoline markets have some degree of Edgeworth price cycling, where large price hikes are followed by small decreases, Maskin and Tirole (1988) suggest that these decreases are caused by a war of attrition between firms attempting to undercut each other. In this regard, price cycles themselves may not necessarily be evidence of anti-competitive behavior. Furthermore, models using weekly data may not pick up these pricing patterns and would not be able to fully identify the dynamics of cost pass-through. Previous papers have explored the role of Edgeworth price cycling in the gasoline market (i.e. Noel (2019, 2007), Eckert (2003)) and found that accounting for the cyclical prices is important in fully understanding the timing of cost pass-through. I expand this research by analyzing how uniform price cycles caused by tacit collusion, instead of competitive undercutting, affects asymmetric price-adjustment and may influence subsequent policy recommendations.

This paper contributes to the literature in two ways. First, I show the importance of considering changes in market conduct in interpreting estimation results from Error Correction Models (ECM). While many gasoline markets in the world have some form of competitive price cycling, the sample used in this paper illustrates how the transition to a cycle with uniform hikes and decreases, adopted by nearly all stations in the market, may affect the magnitude and timing of cost pass-through. In fact, the price cycles observed in Western Australia are more consistent with tacit collusion instead of competitive undercutting. As future studies continue to test for the rockets and feathers effect using new samples and econometric methods, one must distinguish between competitive price cycling and uniform cycling when interpreting results and comparing across literature. Second, my study illustrates additional benefits of using a highly disaggregated dataset for gasoline market analysis by investigating how inference about how the pass-through relationship varies with the use of aggregated data.

The geographic market and institutions in Western Australia are particularly useful for investigating how estimates of the pass-through relationship vary across different model specifications. The dataset, which is described in more detail in section three, includes daily, station-level prices for both retail gasoline, wholesale gasoline, and crude oil which allows me to fully observe the pricing dynamics and pass-through of input price shocks for multiple levels of the distribution chain. This allows for a more thorough analysis of the effect of price cycles that is otherwise lost when using aggregated weekly data. Additionally, the highly disaggregated data allows one to monitor trends, patterns, and shifts in the daily pricing over time; this is particularly relevant when considering tacit collusion among firms. Byrne and de Roos (2019) investigate pricing patterns in the Western Australia gasoline market and find evidence of tacit collusion and price cycling among nearly all gasoline stations within the city after 2011. As such, I investigate the impact of a large-scale market adoption of a uniform price cycle on the pass-through relationship.

Using daily data, I find some evidence of the rockets and feathers effect in the wholesale-to-pump and oil-to-pump relationships but not for the oil-to-wholesale relationship. More specifically, I find statistical evidence of asymmetry in the long-run convergence between wholesale and pay-at-pump price but not in other relationships. When analyzing the timing of the cumulative responses, I find marginal support for the rockets and feathers hypothesis: stations respond faster to a positive shock in wholesale price during the first week. After this point, however, the opposite occurs and the magnitude in response to a negative shock is larger for the remaining weeks.

The cumulative response functions also show evidence of price cycling in the local gasoline market after the initial short-run response; there seems to be a large response approximately every seven days after the shock. In line with Byrne and de Roos (2019), I investigate the pricing patterns and show that shifts in price cycles change the long run relationship and short run dynamics of the model. In addition, aggregating the data to a weekly frequency obscures these patterns and yields entirely different estimate results.

The rest of the paper proceeds as follows. Section II briefly reviews the related literature on the price stickiness, the rockets and feathers effect, and price cycling. Section III describes the dataset and provides initial statistics for the market. Section IV describes the error correction model methodology. Section V provides baseline results. Section VI details changes in pricing patterns and impacts on traditional error correction models. Finally, section VII concludes.

2. Related Literature

I briefly review the related literature in three sections. The first section includes relevant papers looking at the rockets and feathers hypothesis over time, the evidence in favor (or lack thereof), and the general consensus that has emerged over the years. The second section details the previous macroeconomic literature on price stickiness and relevance to the gasoline market. The third section focuses on the Australian gasoline markets, specifically price cycling, and the implications on tacit collusion.

2.1 The rockets and feathers effect

After the two initial papers on asymmetric price pass-through (Bacon (1991), Karrenbrock (1991)), possibly the earliest and most cited paper investigating the rockets and feathers hypothesis is Borenstein, Cameron, and Gilbert (1997), hereafter BCG. Using a series of bivariate error correction models, they test for asymmetry in the speed and magnitude of downstream responses to oil price increases and decreases at different stages of the oil refining process in the USA. Using weekly average prices for 33 cities across the USA, they find strong evidence of asymmetry in the pass-through from crude oil to gasoline spot prices as well as from wholesale gasoline to pay-at-pump prices.

Several authors expanded BCG's work to further test for the rockets and feathers effect in the USA market and abroad. For instance, Balke *et al.* (1998) use weekly data for crude oil, wholesale, and retail gasoline prices, but employ a more general ECM and only find slight evidence of asymmetric pass-through. They offer two potential explanations for why their results differ. Firstly, the timespan for their sample is longer and more recent than that of BCG. Additionally, the results are sensitive to changes in model specification (e.g. allowing for asymmetry in the level variables). Similarly, Bachmeier and Griffin (2003) re-estimate BCG's initial model and find that, even with the same specifications, there is little evidence supporting the rockets and feathers hypothesis when using daily data instead of weekly data. They caution that results are sensitive to the model specification and state that aggregated data can mask the differential response to increases and decreases in input prices.

Later investigations using different markets, models, and data frequencies found mixed results. Strong evidence of asymmetry in the cost pass-through relationship was found by Chen *et al.* (2005), Ye *et al.* (2005), among others, while others Godby *et al.* (2000), Rachenko and Tsurumi (2006) found no support for asymmetry. Moreover, despite improvements in data collection, which have provided access to more disaggregated data, and new time series econometric techniques, no consensus appears to have been reached regarding the rockets and feathers hypothesis (see for instance, Balageuer and Rippollés (2012), Chesnes (2016), Blair *et al.* (2017), Sun *et al.* (2019)).

Recent work by Deltas and Polemis (2020) suggest differences in results may stem from different methodologies, market characteristic, as well as the structure of the data, and systemic differences across time and locations. I contribute to the literature by investigating the role that changes in market conduct under price-cycling play in accounting for differences in the degree of asymmetric pass-through.

2.1 Price Stickiness and Dynamic Pricing

Business cycle models have long included the assumption that prices are sticky in order to generate the short-run non-neutrality of money that appears in empirical macroeconomic literature. However, there are many different explanations for this assumption, including information processing delays (Caballero (1989), Reis (2006)), existence of menu-costs and real rigidities (Barro (1972), Mankiw (1985), Ball and Romer (1990)), or strategic interactions between firms (Rotemberg (2005, 2011). Distinguishing between the sources of these infrequent price-adjustments is key for understanding inflation dynamics and providing appropriate policy recommendations (Reis (2006)). Indeed, more recently Carvalho et al. (2020) show that real rigidities, heterogeneity in price stickiness, and product substitutions can help reconcile frequent individual price changes with slower adjustments in aggregate dynamics.

Using gasoline markets to investigate price stickiness is not new. Several studies employ daily data from Philadelphia's wholesale gasoline market to test for asymmetry in the response to oil price shocks. Davis and Hamilton (2004) and Douglas and Herrera (2010) both conclude that price rigidity in the gasoline market is better explained by strategic interactions and fair pricing instead of the traditional menu-costs. Douglas and Herrera (2014) expand the previous literature by showing that the price stickiness in the market is also consistent with rational inattention by the producer. This paper expands on the previous literature of price rigidity in gasoline markets by introducing an additional pricing strategy of tacitly collusive cycling.

2.2 Pricing patterns in Australian markets

Several investigations into the pricing patterns observed in Australian gasoline markets have contributed to the empirical literature on Edgeworth price cycling during the last decades. The focus in Australia possibly stems from the availability of rich data, as well as from the interesting features of the gasoline market. Indeed, work by Byrne and de Roos (2019) –further discussed in section VI– provides excellent graphical and narrative evidence of tacit collusion in the Perth market. Yet an earlier example of this literature is Wang (2009), who investigates the retail gasoline market in Perth between 2000 and 2003. He finds that the pricing strategies of larger firms, namely price cycles of undercutting nearby rivals and then eventually initiating a restoration phase where stations hike up prices, is consistent with Maskin and Tirole (1988) theory. Additionally, with the implementation of strict timing regulations, he notes that the market fits the setting for tacit collusion in an oligopoly market[1]. Isakower and Wang (2014)

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[1] After 2003, the end of the sample in Wang (2009), price cycles in the gasoline market destabilize and firms have different length phases of undercutting and inconsistent restoration periods, where prices

extend the work of Wang (2009) and shows that these irregular price cycles can also be seen in the liquified petroleum gas market in Perth; however, these cycles typically have a longer phase of undercutting and do not perfectly align with the retail gasoline market. Extending analysis to additional Australian towns, Valadkhani (2013) investigates asymmetric cost pass-through using an error correction model with weekly data and finds some evidence of the rockets and feathers effect in a subsample of towns. However, in a market where prices change on a daily basis, weekly data may hide potential price cycles.

As mentioned earlier, the study by Byrne and de Roos (2019) provides graphical and narrative evidence of tacit collusion in the Perth market. They illustrate that after a period of price leadership in 2011, the majority of gasoline stations stick to a strict pattern of weekly price cycles. While other markets across the world show some evidence of Edgeworth cycling (Zimmerman *et. al* (2013), Noel (2016)), what makes Perth different is that these cycles have an exact, consistent duration of one week. Additionally, the restoration phase of the price cycle is a single, one-day price hike instead of an increase in price spread along multiple days allowing stations to observe if competitors are participating in price increases. Even more interesting is that both types of price cycles can be observed in Perth Australia; prior to 2011 firms engage in competitive pricing strategies with inconsistent price increases whereas after 2011 the majority of stations in the market are synchronized to the same weekly price hike followed by uniform daily price increases. It is the transition between these two forms of price cycling that is of particular interest in this paper.

Recently, more papers have analyzed the unique structures of the Australian gasoline market. Noel (2019) investigates the effect of calendar cycles and consumer demand, comparing

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increase, which are more reflective of a competitive market with price cycles than of a tacitly colluding market.

expenditures between price cycling markets and those without. He finds that consumers may be able to predict future price changes and consequently shift demand to some extent. Valadkhani et al. (2015) find evidence of the rockets and feathers effect in the wholesale diesel market among seaports in Australia. Chua et al. (2017), however, use daily data and only find slight evidence of asymmetry. In line with this body of research, I further the analysis of Australian gasoline markets by using daily, station-level data to investigate the pass-through dynamics and test for asymmetry.

3. Data

The geographical market covered by the data is Perth, Australia, a city of over two million people. Similar to other major cities across the world, there is a concentrated retail gasoline market. Five major companies dominate the wholesale gasoline industry: BP, Caltex, Shell, Mobil, and Puma[2]. Collectively, these five companies own more than 75% of the gasoline stations within Perth. These major firms, and many other smaller companies, have a large number of retail gasoline stations that sell final-stage gasoline to consumers.

Perth is particularly interesting because it has a unique price transparency program called Fuelwatch. Implemented by Western Australia's state government in 2001, the program requires each retail gasoline station to submit all of their next day's prices to the government before 2 p.m. each day. Gasoline retailers are then mandated by law to adhere to these prices for 24 hours starting when they open at 6 a.m. the next morning. In this environment, firms set prices simultaneously and are unable to observe other firms' prices for the next day before submitting their own price. While stations must report their prices for all gasoline products sold, I focus on the dynamics of unleaded petrol (ULP). The reason is two-fold. First, ULP is the most used

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[2] Puma officially controls its own terminal gate after January 1, 2010. Prior to this time the same terminal gate was under control of Gull Petroleum.

commercial gasoline in the market and most likely to impact the consumers. Furthermore, the majority of previous literature has looked at ULP hence facilitating the comparison with earlier studies.

In addition to station level pay-at-pump prices, Fuelwatch also reports daily data for wholesale gasoline prices starting in 2003. Wholesale gasoline sellers, called terminal gates in Perth, act as an intermediary between the refinery process and the final retailer. Wholesalers only sell gasoline by the full tanker load and have a required minimum that makes it infeasible for consumers and companies in non-gasoline industries to purchase directly from them.[3] As such, wholesale prices are a good proxy for a gasoline station's input costs.[4] This is similar to the USA, where the majority of the input costs for retail gasoline is the wholesale price (Borenstein and Shepard (1996)) and where many markets analyzed in the literature have a nearby terminal thus implying transportation costs are minimal (see e.g., Davis and Hamilton (2004)). Furthermore, wholesale prices for Perth constitute the majority of input costs due to the close proximity of the terminal gates to the retail stations. In Perth, all terminal gates are located within 50 km of the city center. In contrast, transportation costs represent a higher percentage of the retail price in cities located far away from a terminal gate. Like the reporting program for retail gasoline stations, wholesalers must set their next day prices by 2 p.m. and are mandated to follow them for 24 hours once they open the next day.

Daily data for station level pay-at-pump and wholesale prices are collected from Fuelwatch from January 2nd, 2003 to December 31st, 2018. In addition to prices, I also collect characteristic data for brand and location. Summary statistics for gasoline and wholesale prices

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[3] For example, in Western Australia BP requires a minimum of 35,000 liters be purchased when ordering from their terminal gate wholesalers.

[4] Average wholesale prices were approximately 73% of the average price of retail gasoline for the USA in June 2019 (EIA (2019)).

can be found in Table 1 and Table 2, respectively. In total, there are eighteen different brands of retail gasoline; however, as mentioned earlier, the top five brands account for more than 75% of the gasoline stations in Perth. On average, there are 301 different gasoline stations active each year with an overall average price of $1.26 per liter over the sample period.

Over the entire sample, six major companies competed at the wholesale level. However, Puma entered the market by completely buying out and absorbing Gull in 2010, thus reducing the number of competing brands to five since 2010. Over the sample the average wholesale price is $1.19 per liter. Since the majority of gasoline stations in Perth are branded, it is important to account for potential contracts between wholesalers and retail stations in order to better estimate input costs. For example, branded stations in the USA may be obligated by contract to buy from a specific wholesaler (traditionally of the same brand or an affiliated company). While the specific terms of these contracts are confidential and unavailable, I control for brands by matching each gasoline station with the corresponding wholesale brand. For example, the wholesale cost used for a BP gasoline station is the BP terminal gate price. However, similar to the USA, not all gasoline stations are branded or are contractually obligated to buy from a certain seller. For independent stations and brands that do not have their own terminal gate, I use the minimum wholesale price for that day as a proxy for input costs.

In order to estimate the pass-through, I also obtain data on the Brent crude oil spot price from the Federal Reserve Economic Database (FRED). I opt for the Brent price over the West Texas Intermediate price because it is the relevant input cost in Australia. Prices are then converted from $US to $AU using the Australian exchange rate from FRED and then converted from $AU/Barrel to $AU/Liter to allow for a direct comparison to wholesale and pay-at-pump prices quoted in $AU/Liter. Since Brent crude oil spot prices are only reported for weekdays, I use the average between the Friday and Monday prices to interpolate oil prices during the weekend.[5] Summary statistics for oil spot price are reported in Table 2.

4. Empirical Methodology

One econometric issue in testing the relationship between crude oil, wholesale, and pay-at-pump gasoline prices is that the time series are likely to be non-stationary. Indeed, results from the Fisher augmented Dickey-Fuller unit root tests reported in Table 3 suggest this is the case for the data analyzed here. Moreover, given the clear input cost linkages among the series, upstream and downstream prices are likely to be cointegrated. As Table 4 shows, the results of Pedroni's Residual Cointegration test for panel data indicate that the series are cointegrated, allowing me to consistently estimate the models with OLS.

Following Engle and Granger (1987) and Balageuer and Rippollés (2016), I begin by estimating the long-run relationship between upstream and downstream prices separately for different stages of refinement (i.e. the relationship between crude oil and wholesale, wholesale and pay-at-pump, and crude oil to pay-at-pump). The following equations are estimated via OLS,

$$PG_{jkt} = \gamma_0 + \gamma_1 PC_{t-1} + \gamma_2 Summer + \sum_{i=1}^{6} \gamma_s Day + \varepsilon_t \tag{1}$$

$$PG_{jkt} = \gamma_0 + \gamma_1 PW_{kt-1} + \gamma_2 Summer + \sum_{i=1}^{6} \gamma_s Day + \varepsilon_t \tag{2}$$

$$PW_{kt} = \gamma_0 + \gamma_1 PC_{t-1} + \gamma_2 Summer + \sum_{i=1}^{6} \gamma_s Day + \varepsilon_t \tag{3}$$

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[5] I also input the missing prices using two alternative methods. The first is a cascade-down method where missing values are replaced by the most recent observation. The second is a cascade-up measurement where missing values are replaced by the next observed value. As a robustness check, I use each series instead of the average and find no significant differences in results.

where PG_{jkt} is the price of gasoline for station *j* of brand *k* at time *t*, PC_t is the price of crude oil at time *t*, and PW_{kt} is the price of wholesale gasoline for brand *k* at time *t*. *Summer* is a dummy variable indicating if the observation is between December 1st and March 1st while *Day* is a dummy variable for the day of the week. Since pay-at-pump and wholesale prices are both set the prior day, the input price is lagged by one day for each stage above.[6]

Then, to estimate short-run dynamics that allow for a different speed of adjustment for positive and negative up-stream prices, I estimate the following error correction models:[7]

$$\Delta PG_{jkt} = \sum_{i=0}^{m^+} \beta_{ci}^{+} \Delta PC_{t-i}^{+} + \sum_{i=0}^{m^-} \beta_{ci}^{-} \Delta PC_{t-i}^{-} + \sum_{i=1}^{n^+} \beta_{gi}^{+} \Delta PG_{jkt-i}^{+} + \sum_{i=1}^{n^-} \beta_{gi}^{-} \Delta PG_{jkt-i}^{-} + \theta^{+} z_{1,t}^{+} + \theta^{-} z_{1,t}^{-} + \lambda_j + \varepsilon_{jt} \tag{4}$$

$$\Delta PG_{jkt} = \sum_{i=0}^{m^+} \beta_{wi}^{+} \Delta PW_{kt-i}^{+} + \sum_{i=0}^{m^-} \beta_{wi}^{-} \Delta PW_{kt-i}^{-} + \sum_{i=1}^{n^+} \beta_{gi}^{+} \Delta PG_{jkt-i}^{+} + \sum_{i=1}^{n^-} \beta_{gi}^{-} \Delta PG_{jkt-i}^{-} + \theta^{+} z_{2,t}^{+} + \theta^{-} z_{2,t}^{-} + \lambda_j + \varepsilon_{jt} \tag{5}$$

$$\Delta PW_{kt} = \sum_{i=0}^{m^+} \beta_{ci}^{+} \Delta PC_{t-i}^{+} + \sum_{i=0}^{m^-} \beta_{ci}^{-} \Delta PC_{t-i}^{-} + \sum_{i=1}^{n^+} \beta_{wi}^{+} \Delta PW_{kt-i}^{+} + \sum_{i=1}^{n^-} \beta_{wi}^{-} \Delta PW_{kt-i}^{-} + \theta^{+} z_{3,t}^{+} + \theta^{-} z_{3,t}^{-} + \lambda_k + \varepsilon_{kt} \tag{6}$$

where the + and – superscripts denote a positive or negative price change. ΔPG_{jkt} is the change in the price of retail gasoline for station *j* of brand *k* at time *t*. Similarly, ΔPW_{kt} is the change in the price of wholesale gasoline for brand *k* at time *t* and ΔPC_t is the change in the price of crude oil at time t. Note that the estimation strategy allows for possible heterogeneity of price-setting behavior across the retail gasoline stations (*j = 1, 2,… ,N)*. As usual, the error correction terms

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[6] As a robustness check, I also run the models for contemporaneous relationship and do not find any significant differences in results.

[7] For similar specifications, see Borenstein *et al.*, 1997 and Balaguer and Ripollés, 2016.

z_t^+ and z_t^- are the corresponding residuals from the estimated long-term relationships from equations (1) – (3) split into positive and negative shocks. θ^+ and θ^- represent the speed of convergence to the long-run equilibrium for a short-run price above and below equilibrium, respectively. Finally, ε_{jt} is a random error term, which is assumed to be *i.i.d.* The number of lags is selected using Bayesian Information Criterion (BIC) with a maximum number of 14 lags.[8] The baseline ECM is estimated via OLS.

5. Baseline Results

Estimation results reported in Table 5 provide statistical evidence of a long-run relationship between the input costs and product sold. Three characteristics stand out. First, the results point towards a more than one-to-one pass-through in the long run. For example, a one cent per liter change in crude oil prices is estimated to result in a change in wholesale price of 1.045 cents and an eventual change in pay-at-pump prices of 1.079 cents. Similarly, a one cent change in wholesale price is associated with a change in pay-at-pump prices of 1.051 cents. Second, strong evidence of a price cycle based on the day of the week is found for wholesale and retail prices. All day of the week dummies are significant in models (1) and (2) while only some are significant in model (3). This result reflects the fact that price cycling takes place at the retail level. Finally, as one would expect, prices increase during the summer when driving is more prevalent. Note how the summer dummies are positive and statistically significant in all models.[9]

Results for the key coefficients in each of the error correction models are presented in Table 6. For the sake of brevity and because I am interested in investigating the potential for

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[8] I allow for further asymmetry within the model by allowing for different numbers of lags for the positive and negative price changes, as denoted by m^+ and m^-. In doing so I find that a lag length of 14 days minimizes the BIC for the models above.

[9] The residuals from models (1) – (3) are recorded and used to account for the long-run adjustment process in the error correction models.

weekly price cycles, I report the estimated coefficients on the input price lagged three days, one week, and two weeks after the shock.[10] To begin, I investigate whether there is asymmetry in the first period response to a shock in input prices. More specifically, I test whether the first period response to a positive shock in input price is statistically different than that to a negative shock of the same magnitude (i.e., H_0: $\Delta PW_1^+ = \Delta PW_1^-$ or H_0: $\Delta Oil_1^+ = \Delta Oil_1^-$ for the corresponding model). As Table 7 illustrates, I only find evidence of a contemporaneous asymmetry in the pass-through from crude oil to retail gasoline.

While finding little evidence of contemporaneous asymmetry might not be surprising, as prices might be somewhat sticky in the short run, a number of studies using weekly or monthly data have found evidence of asymmetry, suggesting that temporal aggregation, possibly in conjunction with greater asymmetry in the long run, could result in finding contemporaneous asymmetry when using lower frequency data. To explore this issue further, I test for asymmetry in the long-run adjustment process. As Table 6 illustrates, in each model, the coefficients for Z^+ and Z^- have the correct sign but differ in magnitude. Interpretation is straight forward. For the crude oil to retail gasoline relationship (column (1) of Table 5), for example, the coefficient on Z^+ is -0.0224 indicating that when the actual price is above the long-run equilibrium, it converges very slowly towards the equilibrium. A reduction of 2.24% of the difference takes place each day, which implies that it would take approximately 45 days for the price to return to the pre-shock value, all else equal. However, the coefficient on Z^- indicates that when the actual price is below the equilibrium, it converges at a faster rate of 5.24% of the difference each day (which implies that it would only take approximately 19 days to return to the pre-shock value). Evidently, the convergence rate from below the long-run equilibrium is greater than that from

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[10] Estimation results for other days are available from the author upon request.

above for all specifications. In other words, after an input price shock, gasoline stations are quicker to raise prices when below the long-run equilibrium than they are to lower prices when above it. In other words, there is evidence of asymmetry in the long run. In other words, this result falls in line with the "rockets and feathers" phenomena.

Table 8 presents results for tests of equality of the error correction coefficients, where the null hypothesis is H_0: $\theta^{+} = \theta^{-}$. I find evidence of asymmetry in the long-run dynamics for the relationships between oil and retail gasoline as well as from wholesale to retail gasoline. However, there is no evidence of long-run asymmetry when testing the pass-through from crude oil and wholesale.

Asymmetry may not only be evident in the magnitude of the response to positive and negative cost changes, but also in the timing of the price pass-through and thus might only be evident in the cumulative response after a certain period of time Hence, I compute the cumulative response to dig deeper into the dynamics of the pass-through. To facilitate the comparison of the responses to positive and negative shocks, I plot both responses in the first quadrant. Figure 1 presents the cumulative response function (CRF) for the crude oil-retail, wholesale-retail, and crude oil-wholesale relationships. Pointwise confidence bands are computed with a block bootstrap with 2000 repetitions (Gonçalvez (2011)). The area between the red (blue) lines represent the middle 90% of all repetitions for a positive (negative) shock in input prices.

Panel (a) of Figure 1 illustrates the pass-through relationship from crude oil to pay-at-pump price. Even after accounting for days of the week in the long-run model, it is evident that the Perth gasoline market exhibits Edgeworth price cycling. In other words, prices for the market as a whole generally follow the same pattern: on average, the firms exhibit a weekly price hike that is then followed by a slow and gradual reduction in prices over the following days until the next price hike occurs. This can be seen in the ripples at the top of the CRF after the initial response to the cost shock in the first ten days. For Perth, the gasoline price hike traditionally occurs in the middle of the week (Wednesday or Thursday); prices then gradually fall during the next seven days before jumping up again. Interestingly, overall the response to a decrease in oil prices is not only faster but also larger in magnitude than the response to an increase, which goes against "rockets and feathers"

Panel (b) reveals a small period where the response to a positive price shock is significantly higher than the response to an equivalent negative shock. This behavior is consistent with the rockets and feathers hypothesis; however, when looking at the magnitudes of the cycles after the first week, the response to a negative input shock is larger than that to a positive shock, similar to panel (a). The weekly price cycling can be seen more clearly in the wholesale to retail relationship and occurs for the responses to both the positive and negative input price shocks. A possible explanation for this inverse rockets and feather affect, which will be expanded in more detail in the following section, is that the uniform price cycle adopted in the latter half of the sample locks firms into regular price decreases and prevents firms from responding to positive cost-shocks as quickly.

Panel (c) of Figure 1 illustrates the response of wholesale prices to a shock in crude oil price. A couple key insight may be derived from the figure. First, there does not seem to be any evidence of price cycling occurring here. Instead of a weekly hike in response to a positive shock, the CRF show a sharp, initial hike followed by a smooth, gradual decrease to long-run equilibrium. Secondly, there is no evidence of significant asymmetry in the pass-through relationship. When comparing across the three response functions, it is evident that asymmetric price pass-through may occur downstream between wholesale and pay-at-pump for this market; however, the price cycles make it difficult to separately identify this asymmetry. Therefore, in the next section, I investigate how changes in market structure, such as the transition from competitive price cycling to a uniform price cycle, may impact results from traditional error correction models.

6. The Evolution of Pass-Through and Changes in Pricing Patterns

One explanation for the inverse rockets and feathers effect discussed in the previous section is that, over time, firms change how they set their prices (e.g., they may be less responsive to changes in input prices). Indeed, Byrne and de Roos (2019) -hereafter BR19- provide graphical evidence to illustrate the development of pricing patterns between January of 2010 and January of 2013 within the Western Australia gasoline market. In brief, they show how BP becomes a price-point leader in the market by initiating a Wednesday price jump (a one-day increase in prices of over 6 cents per liter) in early 2010; the remaining gasoline stations then exhibit a corresponding and equivalent price jump on Thursday, one day later. Prior to this period, some firms exhibited similar competitive price cycles with periods of restoration and undercutting, but no one firm was consistently a price leader, nor could firms perfectly predict the day of the next price hike. Between 2010 and 2013, BP gradually transitioned to Thursday price jumps, like the other brands, thus creating a unified price cycle in the gasoline market. Figures 2a and 2b provide an example of this transition and illustrate the BP price leadership in 2011 and unified cycles in 2013.

This new market conduct is different from previous, competitive cycles in a few ways. Firstly, while other markets with Edgeworth cycling include restoration phases that can occur over multiple days (Lewis and Noel (2011)), the restoration period here regularly occurs as a uniform, single-day price hike. Additionally, in the traditional undercutting phase, stations consistently decrease their price by the same amount each day instead of attempting to predict and undercut competitors. As such, the new price cycles show potential evidence of tacit collusion.

6.1 Long-Run Relationships and Uniform Price Cycling

I empirically inquire into the evolution of the long-run relationship and the adoption of a uniform price cycle across all brands. Note that while there is slight evidence of price cycling in the oil to wholesale relationship, BR19 find that tacit collusion occurs at the retail gasoline station level; as such, I focus on the relationship between wholesale gasoline and pay-at-pump prices. To begin, I estimate equation (2) using a rolling window of six years and plot the coefficient on the wholesale price to gain some insight as to how using a different sample period would affect the estimates and inference regarding the long-run relationship between retail and gasoline prices. The first subsample corresponds runs from January 3, 2003 to January 3, 2009, whereas the last subsample spans the period between December 31, 2012 and December 31, 2018. Figure 4 illustrates the impact on the pay-at-pump price for each day of the week across the rolling window analysis.[11] I denote two important dates using a red vertical line. The first date is January 1, 2004; subsamples that begin prior to this date do not include the stable, BP-led price leadership nor the cycles that begin in 2010. The second point is January 1, 2010; subsamples that begin after this period *only* include observations during this uniform cycle. Points in-between these two vertical lines indicate that the subsample includes observations during the transition period and cover days before and after the 2010 shift.[12]

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[11] The horizontal axis indicates the first day for each panel. This would include that date as well as the six years of data afterwards. For example, 1/3/04 indicates a window from 1/3/04 to 1/3/10.

[12] The further along the X-axis, as it approaches 1/1/10, the more observations of price leadership and price cycling are including in the window.

In the earlier subsamples I find small, positive coefficients for most dummy variables. This suggests that there is no specific day of the week when gasoline stations uniformly increase their prices. In other words, there is no evidence of cycling in the earlier subsamples. As the window moves forward, however, a pattern emerges. First, while the coefficients for the latter half of the week increase, the coefficients on the other days of the week fall below zero. For example, the estimates imply that gasoline is more expensive on Thursday than any other day of the week for the subsample beginning in 1/1/10. This result provides statistical evidence supporting BR19 graphical evidence indicating that firms uniformly initiate a price hike on Thursdays. Second, in the latest subsamples I find evidence of a shift in the timing of the restoration phase; the coefficients for Tuesday and Wednesday gradually increase, indicating that price hikes occurred on those days. As BR19 note, firms gradually switch the date of their price hikes late in the sample, which can be seen by the sharp increase in the impact for that day of the week.

Overall, the estimation results depicted in the figure illustrate how inference regarding the long-run relationship between wholesale and retail gasoline changes dramatically depending on the sample used for estimation. A possible explanation for this result (see BR19) is that the shift in the weekly pattern was due to the transition to a uniform price cycle. In doing so, cyclical patterns became much more important component of the price of gasoline.

Figure 4 repeats the rolling window analysis and reports γ_1, the coefficient on wholesale price, for each subsample. As in the previous figure, it is clear that the pass-through coefficient varies over time: in the earlier subsamples the coefficient is greater than one suggesting a more than one-to-one pass-through, whereas in the later subsamples drops below one. The time-varying nature of this coefficient is indicative of a change in the firm pricing strategies and an increased emphasis on changing prices on a particular day of the week instead of immediately following changes in input costs[13].

The finding that firms transition to a uniform price cycle starting in 2010 is not new (see BR19). Yet, the estimation results reported here provide statistical evidence of the change from competitive price cycling to uniform cycles under leadership. In the earlier periods there was not a consistent price leader and as such brands initiated their price hikes on different days of the week. As such, it was more difficult for a firm to perfectly predict when the next price hike would be initiated; this can be seen by how the long-run effect of the day-of-the-week variables are not economically significant. However, as BP becomes a long-term leader and firms transition to a synchronized cycle, the day of the week quickly becomes a key part of pay-at-pump price dynamics. Firms are less likely to respond to large changes in wholesale or input costs because they are tacitly committed to a price cycle. The increased explanatory power of the day-of-the-week dummies is evident in the increased magnitudes of the coefficients[14]

6.2 Robustness Checks: Price Cycle Changes and Time Aggregation

In this section, I describe a series of alternative models estimated to investigate how a uniform price cycle impacts traditional testing differently than traditional competitive pricing patterns.

First, I split my sample at January 1, 2010 to form two subsamples; the earlier half of the sample corresponds to the period prior to BP acting as a consistent price leader while the latter half takes place entirely during the uniform price cycle adopted by all firms. I re-estimate models

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[13] This can also be seen in the correlations during this time period. The correlation between day-of-the-week and retail price increases from 0.01 to 0.10 after price cycling; at the same time correlation between input cost and retail price decreases from 0.95 to 0.84.

[14] Similar results have been found in other markets. For instance, Kim and Cotterill (2008) find that under collusion, cost pass-through in the processed cheese market fell from between 73%-103% to 21%-31% when compared to Nash-Bertrand price competition.

(2) and (5) for each of the subsamples in order to compare how the dynamics differ. Table 9 reports the long-run coefficients from model (2). Similar to the results from the rolling window analysis, I find that the long-run passthrough coefficient is significantly lower for the latter period than for the earlier period.

Figure 5 reports the cumulative response functions using the subsamples; in order to investigate potential changes in the early short-run response, I focus on the first three weeks after the shock instead of the long-term ripples that are primarily responses to the price cycles. Panel (a) of Figure 5 shows that for the full sample, in general, there is little support for the rockets and feathers hypothesis within the first three weeks. The only horizon where the magnitude of the response to a positive input shock is higher than the response to a negative shock is after one week; elsewhere it is either insignificant or significant for the inverse of the rockets and feathers effect: the magnitude of the response to a negative shock is significantly higher than the response to an equivalent positive shock. Panels (b) and (c), illustrating before and after price cycling, give a clearer idea of what is going on.

In the earlier subsample, there is significant evidence supporting the rockets and feathers hypothesis for the first three days after the shock as well as one week after the shock. This means that before market conduct shifts to a uniform price cycle in 2010, on average firms were faster to respond to positive input price shocks than negative shocks for the first three days. Furthermore, the same effect occurs one week after the shock. When looking at the later subsample in panel (c), however, the responses are very different. There is slight evidence of the rockets and feathers effect in play, but it does not occur until three days after the shock. Table 10 shows the results from testing for asymmetry in the contemporaneous responses; similar to the CRF, we see evidence for the rockets and feathers effect only for the earlier subsample. When looking at the full sample, not accounting for changes in the market structure, these responses become less clear and significance is largely lost. I show that by not accounting for changes in price structures, one might overlook statistical support for the rockets and feathers hypothesis in the contemporaneous effect and short run dynamics.

Additionally, as mentioned by Deltas and Polemis (2020), the level of temporal aggregation of the data can dramatically change the results. To test this, I aggregate the data to the weekly level by taking the average price from a Sunday to Sunday period and reestimating models (2) and (5) without the day-of-the-week variables.[15] Table 9 shows that the long-run coefficient for the weekly model has the same sign and magnitude as in model (2). The short-run dynamics, however, show strong evidence of the anti-rockets and feathers effect; in both the contemporaneous response (Table 9) as well as in the CRF (Figure 5 panel (d)), retail prices appear to respond much faster to negative price shocks than their positive counterparts. However, as was shown in the previous models using disaggregated data, this is not the case. As such, it is important to use the most disaggregated data available in order to fully observe the pass-through relationship.

7. Conclusion

Using a multi-staged error correction model, I test for evidence of the Rockets and Feathers effect using disaggregated data from Western Australia. I find statistical evidence of asymmetry in the contemporaneous response of pay-at-pump price to crude oil but not for any other relationship. Furthermore, I find statistical evidence of asymmetry in the long-run convergence between wholesale and pay-at-pump price but not in the others relationships.

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[15] I have also transformed the data by recording the price at a specific, constant day-of-the-week and results are still robust.

When analyzing the cumulative response functions, it is evident that the market for gasoline in Western Australia follows an Edgeworth price cycle. Lewis and Noel (2011) show that cycling markets behave differently than non-cycling markets and that not accounting for the Edgeworth price cycles can dramatically overestimate the time it takes to fully absorb an input price shock. Furthermore, while price cycling is common in many gasoline markets across the world, the Perth gasoline market transitions from competitive price setting to a uniformly consistent and stable price cycle adopted by nearly all stations in the market; this latter price cycle being potential evidence of tacit collusion. The CRF for the relationship between wholesale and retail gasoline shows a slight asymmetry; the first week shows evidence of the rockets and feathers effect but subsequent weeks do not. However, the CRF for the relationship between oil and retail gasoline describes the opposite asymmetry in price pass-through. Overall, the Western Australian gasoline market does not show strong evidence of the rockets and feathers effect. These results are robust to accounting for number of nearby firms, location to major roadways, as well as alternatively model specification.[16]

To investigate how the evolution of the retail gasoline market described in Byrne and de Roos (2019) affects these results, I estimate the model using a rolling window scheme. Not surprisingly, I find important changes in the short-run and long-run dynamics for the estimated parameters over the sample period. After splitting the sample into periods before and after the adoption of a uniform price pattern, I show that not accounting for differences in timing can lead to insignificant results and a lack of evidence for the rockets and feathers effect. Similarly, I illustrate how weekly data are not able to fully capture the short-run dynamics of the market and

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[16] For these tables and graphs, see Online Appendix.

as such the results from those models may not be completely representative of the pass-through relationship.

While Deltas and Polemis (2020) mention a variety of different reasons why previous literature has failed to find a consensus, this paper offers additional explanatory factors. As Wang (2009) and Byrne and de Roos (2019) show, the market structure with perfect monitoring of rivals creates an ideal market for tacit collusion. Future research that wishes to yield policy recommendations from asymmetric cost pass-through in markets with price cycles must be careful to distinguish between competitive undercutting price cycles and uniformly adopted ones, the latter being potential evidence of anti-competitive behavior.

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Table 1: Summary Statistics for Retail Gasoline Stations

Brand	Mean (AU$/L)	Standard Deviation	Number of Stations (Avg.)	Number of Observations
BP	1.27	0.188	67.8	395,304
Caltex	1.263	0.19	58.8	343,583
Coles Express	1.301	0.168	48.7	266,398
Puma	1.281	0.176	35.3	205,859
Woolworths	1.275	0.181	21.5	125,399
7-Eleven	1.336	0.146	12.4	18,059
United	1.302	0.144	12.2	71,445
Independent	1.306	0.236	12	70,068
Peak	1.147	0.191	9.3	54,549
Gull	1.203	0.202	8.8	51,375
Mobil	1.094	0.18	4.9	28,351
Shell	1.055	0.215	4.9	28,779
Ampol	1.059	0.158	4.9	14,330
Better Choice	1.274	0.167	4.2	24,713
Liberty	1.18	0.212	4	18,837
Vibe	1.295	0.145	2.9	17,158
Wesco	1.233	0.206	2.6	15,000
Kwikfuel	1.247	0.178	1	6,023
FastFuel 24/7	1.298	0.156	0.9	3,032
Swan Taxis	1.037	0.134	0.9	1,276
Total	1.263	0.191	301.29	1,759,538

Note: This table reports the summary statistics for the retail gasoline stations in Perth, Australia. Brands in bold are the five largest competitors in the market.

Table 2: Summary Statistics for Wholesale and Brent Oil Prices

Brand	Mean (AU$/L)	Standard Deviation
BP	1.202	0.165
Caltex	1.209	0.169
Mobil	1.204	0.163
Shell	1.180	0.163
Puma	1.260	0.123
Gull	1.118	0.177
Total	1.198	0.165
Brent Crude Oil	0.529	0.149

Note: This table reports the summary statistics for the wholesale providers in Perth, Australia as well as the Brent Crude Oil price.

Table 3: Unit Root Tests

			First Difference	
	Statistic	P-Value	Statistic	P-Value
Gasoline Price	721.778	1.0000	61202.7	0.0000
Wholesale Price	950.757	1.0000	48848.7	0.0000
Oil Price	1170.95	0.6476	60052.6	0.0000

Note: Results are from the Fisher augmented Dickey-Fuller unit root test for panel data where the null hypothesis is the presence of a unit root.

Table 4: Cointegration Tests

	Retail		Wholesale	
	Statistic	P-Value	Statistic	P-Value
Wholesale	117.5207	0.000	---	---
Crude Oil	126.6951	0.000	134.6455	0.000

Note: This table reports the results of Pedroni’s Residual Cointegration Test for panel data. The null hypothesis is no cointegration.

Table 5: Long-Run Relationship Estimates

	Oil on Pump	Wholesale on Pump	Oil on Wholesale
	(1)	(2)	(3)
Brent Oil	1.079***		1.045***
	(0.0029)		(0.0213)
Wholesale		1.051***	
		(0.0017)	
Summer	-0.651***	0.566***	-1.042***
	(0.0271)	(0.0250)	(0.0500)
Monday	-1.333***	-1.332***	0.0017
	(0.0366)	(0.0367)	(0.0020)
Tuesday	2.223***	2.203***	0.0520***
	(0.0900)	(0.0900)	(0.0118)
Wednesday	1.491***	1.378***	0.129***
	(0.0720)	(0.0721)	(0.0188)
Thursday	3.651***	3.522***	0.125***
	(0.1060)	(0.1060)	(0.0245)
Friday	2.524***	2.510***	0.0018
	(0.0645)	(0.0645)	(0.0101)
Saturday	1.151***	1.149***	-0.00871*
	(0.0327)	(0.0322)	(0.0042)
Constant	68.53***	-0.114	64.76***
	(0.1550)	(0.2080)	(1.1400)
Obs.	1757884	1757884	29207
R-squared	0.7620	0.8830	0.9060
IDs	600	600	6

Notes: Column (1) reports the estimate for equation (1), which corresponds to the long-run relationship between retail gasoline prices and crude oil price; column (2) the relationship between wholesale gasoline and retail gasoline (equation 2), and column (3) the relationship between crude oil and wholesale gasoline (equation 3). Robust standard errors in parentheses.

(*** p<0.01, ** p<0.05, * p<0.1)

Table 6: Key Estimates for the Error Correction Models[17]

Oil on Pump		Wholesale on Pump		Oil on Wholesale	
(1)		(2)		(3)	
ΔOil_1^+	0.0411***	ΔPW_1^+	0.268***	ΔOil_1^+	0.00373
	(0.00455)		(0.00681)		(0.00481)
ΔOil_1^-	0.0266***	ΔPW_1^-	0.268***	ΔOil_1^-	-0.00701
	(0.00432)		(0.00847)		(0.00393)
ΔOil_2^+	-0.0735***	ΔPW_2^+	0.250***	ΔOil_2^+	0.0223*
	(0.00440)		(0.00765)		(0.0104)
ΔOil_2^-	0.0182***	ΔPW_2^-	0.220***	ΔOil_2^-	-0.00360
	(0.00424)		(0.00748)		(0.00549)
ΔOil_3^+	-0.0489***	ΔPW_3^+	0.223***	ΔOil_3^+	0.0381**
	(0.00418)		(0.00657)		(0.0135)
ΔOil_3^-	0.0117***	ΔPW_3^-	0.221***	ΔOil_3^-	0.0308***
	(0.00446)		(0.00839)		(0.00373)
	…		…		…
ΔOil_7^+	0.0841***	ΔPW_7^+	0.267***	ΔOil_7^+	0.141***
	(0.00637)		(0.00792)		(0.00694)
ΔOil_7^-	0.0334***	ΔPW_7^-	0.210***	ΔOil_7^-	0.141***
	(0.00523)		(0.00755)		(0.0109)
	…		…		…
ΔOil_{14}^+	0.177***	ΔPW_{14}^+	0.110***	ΔOil_{14}^+	0.0142
	(0.00566)		(0.00607)		(0.0117)
ΔOil_{14}^-	0.200***	ΔPW_{14}^-	0.255***	ΔOil_{14}^-	0.0129
	(0.00632)		(0.00808)		(0.0105)
Z^+	-0.0224***	Z^+	-0.00741***	Z^+	-0.00559**
	(0.00169)		(0.00186)		(0.00168)
Z^-	-0.0524***	Z^-	-0.101***	Z^-	-0.0141***
	(0.00150)		(0.00417)		(0.00316)
Constant	-0.163***	Constant	-0.264***	Constant	-0.0219
	(0.0158)		(0.0212)		(0.0155)
Obs.	1,741,936	Obs.	1,741,936	Obs.	29,138
R^2	0.735	R^2	0.751	R^2	0.236
IDs	597	IDs	597	IDs	6

Note: Column (1) reports the estimate for equation (4), which corresponds to the ECM for retail gasoline prices on crude oil price; column (2) the relationship between wholesale gasoline and retail gasoline (model 5), and column (3) the relationship between crude oil and wholesale gasoline (model 6). Robust standard errors in parentheses. (*** p<0.01, ** p<0.05, * p<0.1)

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[17] Full table of all coefficients available in online appendix.

Table 7: Testing Asymmetry in Contemporaneous Response

	H_0: ß$_i$ = 0		H_0: ß$_i^+$ = ß$_i^-$	
Relationship	P-Value (Input$^+$)	P-Value (Input$^-$)	Statistic	P-Value
Oil to Pump (ß$_{c1}$)	0.0410***	0.0265***	3.81	0.0514*
Oil to Wholesale (ß$_{c1}$)	0.0037	-0.0070	2.07	0.2093
Wholesale to Pump (ß$_{w1}$)	0.2680***	0.2676***	0.000	0.9690

Note: This table reports the results from testing for asymmetry in the contemporaneous response in equations (4)-(6).

(*** p<0.01, ** p<0.05, * p<0.1)

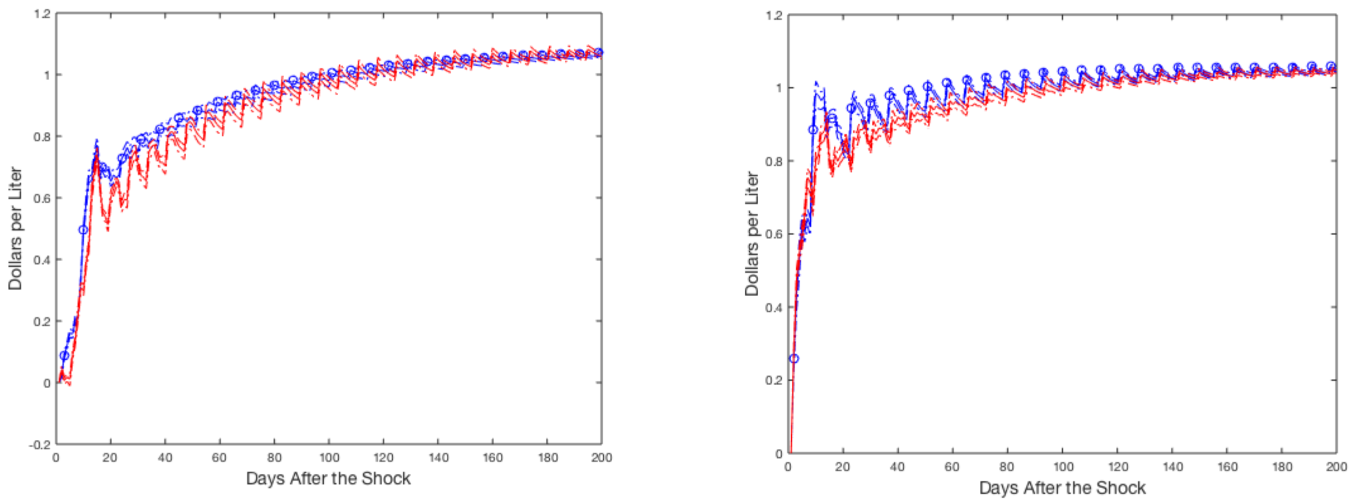
Table 8: Testing Asymmetry in Long-Run Convergence Rates

	H_0: $\theta_i = 0$		H_0: $\theta_i^+ = \theta_i^-$	
Relationship	P-Value (Z^+)	P-Value (Z^-)	Statistic	P-Value
Oil to Pump	-0.0223***	-0.0523***	193.37	0.0000***
Oil to Wholesale	-0.0055**	-0.0141***	3.59	0.1165
Wholesale to Pump	-0.0074***	-0.1014***	303.06	0.0000***

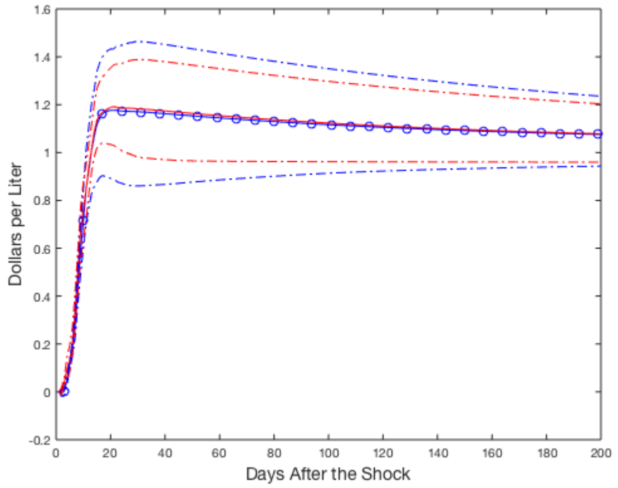
Note: This table reports the results from testing for asymmetry in the long-run convergence rates in equations (4)-(6).

(*** p<0.01, ** p<0.05, * p<0.1)

Figure 1: Cumulative Response Functions for Error Correction Models


(a) Response of Retail to $1 Shock in Oil

(b) Response of Retail to $1 Shock in Wholesale

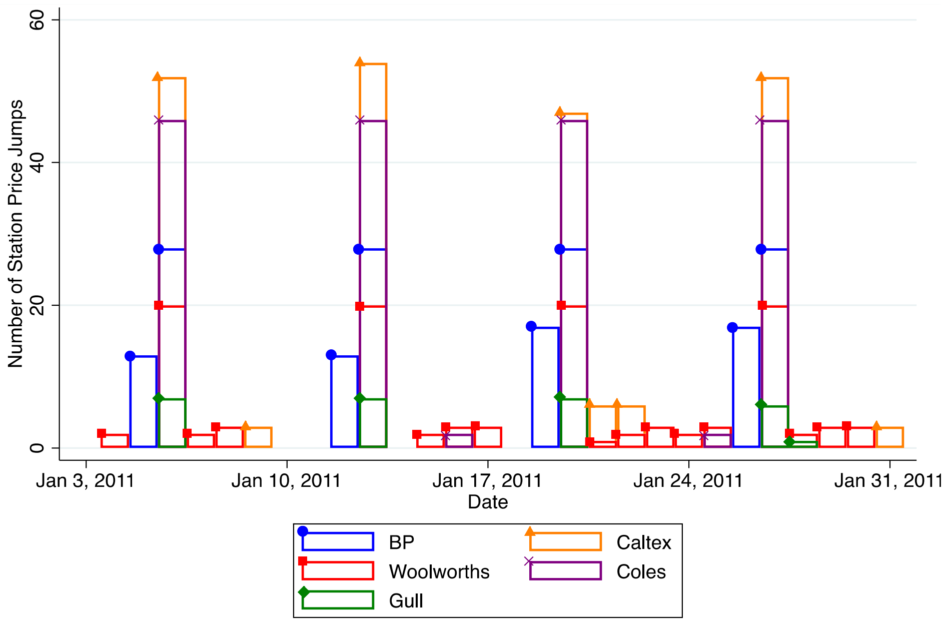

(c) Response of Wholesale to $1 Shock in Oil

Note: This figure illustrates the cumulative responses of the downstream prices to a $1 positive (solid red line) and a $1 negative shock (circle-solid blue line) in the upstream price. The dashed lines represent 90% confidence bands computed using a block-bootstrap.

Figure 2: Graphical Example of BP Price Leadership and Uniform Price Cycling

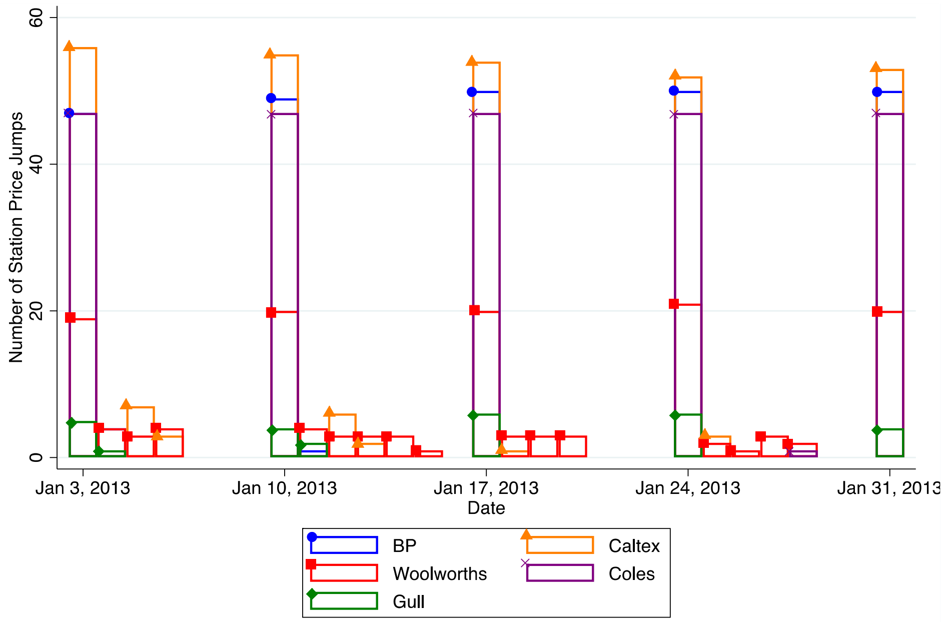
(a)

Price Jumps in January, 2011 (Price Leadership)



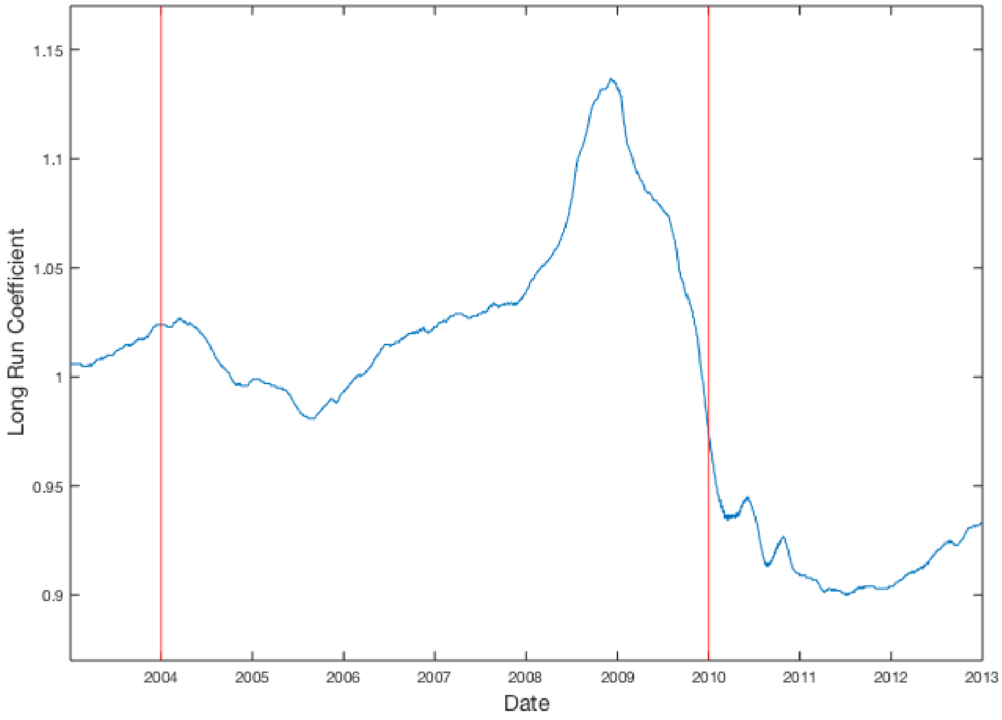
(b)

Price Jumps in January, 2013 (Price Cycling)



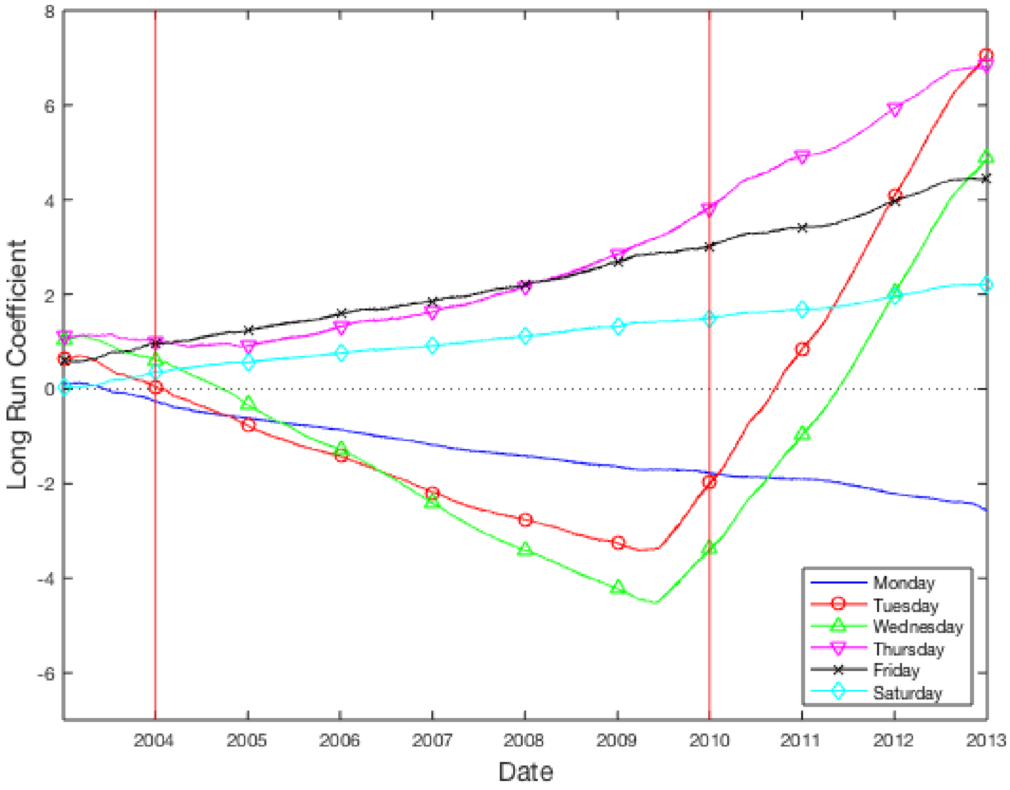
Note: This figure shows the frequency and timing of price jumps, measured as a one-day change in price of seven cents or more, during BP price leadership and uniform price cycling.

Figure 4: Long Run Cost Pass-Through (Rolling Window)



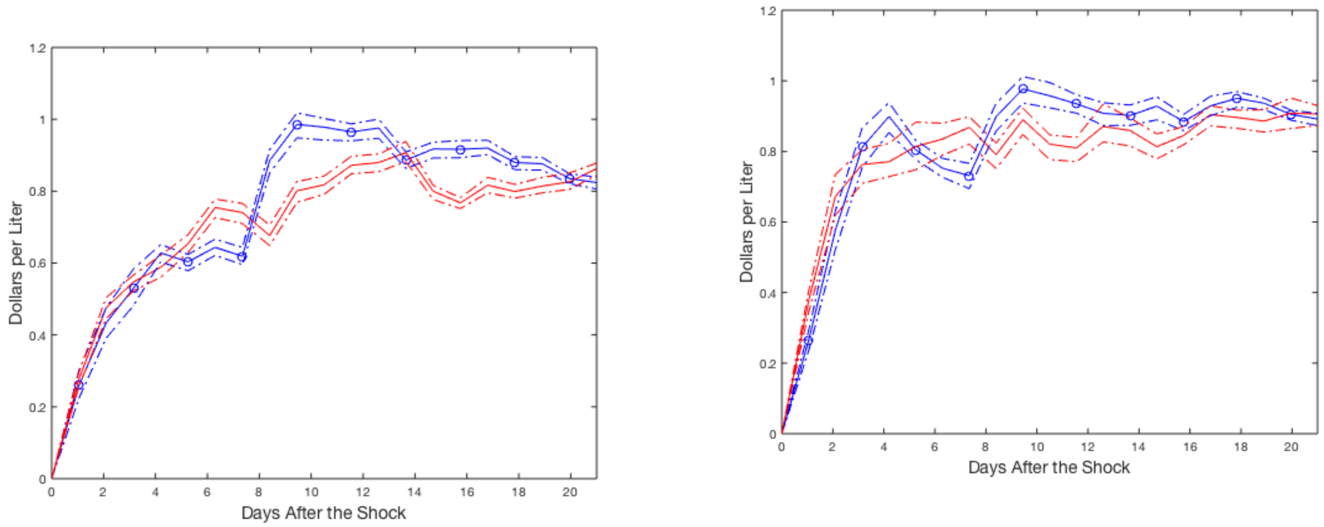
Note: This figure plots the long-run coefficient estimates for the relationship between wholesale gasoline price and retail gasoline price using a rolling window framework. The date on the horizontal axis is the first date within the six-year window. The vertical lines at 2004 and 2010 represent when the windows begin to contain observations of price leadership and when the window is entirely made up of observations of price cycling.

Figure 3: Day of the Week Price Coefficients (Rolling Window)



Note: The figure above plots the long-run coefficient estimates on the day of the week dummy variables under a rolling window framework. Date on the horizontal axis is the first date within the six-year window. The vertical lines at 2004 and 2010 represent when the windows begin to contair observations of price leadership and when the window is entirely made up of observations of price cycling.

Figure 5: Cumulative Response Functions for Pre-Period, Post-Period, and Weekly

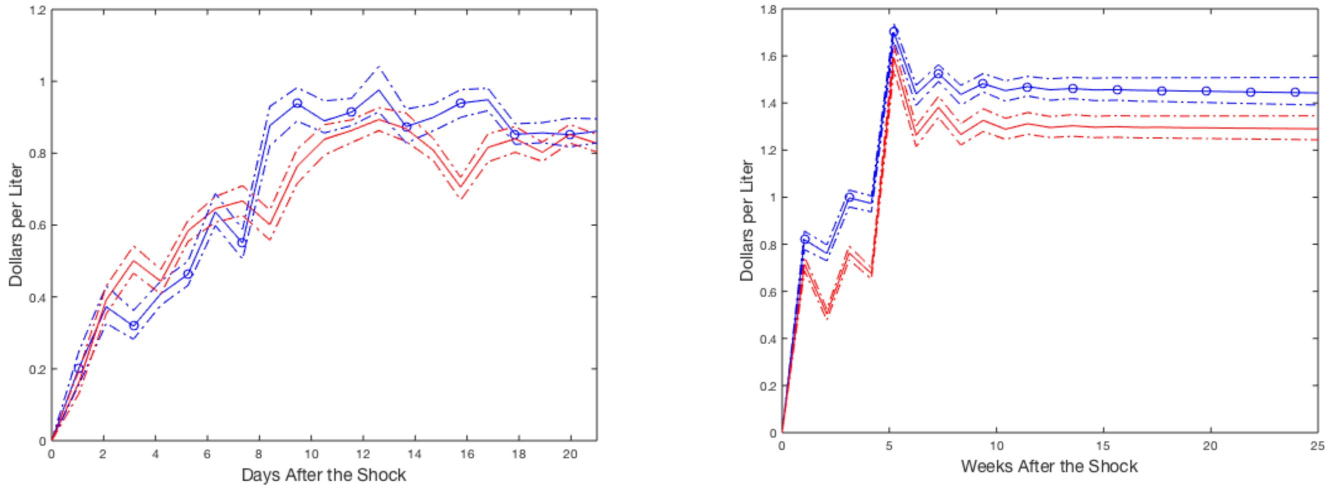


(a)

Response of Retail to $1 Shock in Wholesale
(3 Weeks)

(b)

Response of Retail to $1 Shock in Wholesale
(3 Weeks, Pre-Period)



(c)

Response of Retail to $1 Shock in Wholesale
(3 Weeks, Post-Period)

(d)

Response of Retail to $1 Shock in Wholesale
(Weekly Data)

Note: Figures above illustrate the cumulative responses over time of the retail price to a $1 positive and negative shock in wholesale gasoline price, specifically for the first three weeks after the shock. Panel (a) estimates across the entire sample, panel (b) estimates the earlier subsample up until BP price leadership begins in 2010, and panel (c) estimates the later subsample that begins in 2010. Confidence bands report the 5th and 95th percentiles after bootstrapping 500 repetitions.

Table 9: Long Run Relationship Estimates, Pre, Post, and Weekly

	Pump Price (Daily, Pre 2010)	Pump Price (Daily, Post 2010)	Pump Price (Weekly)
	(1)	(2)	(3)
Wholesale	1.003***	0.925***	1.051***
	(0.0019)	(0.0026)	(0.0017)
Summer	0.261***	0.116***	0.507***
	(0.0285)	(0.0303)	(0.0251)
Monday	-0.0963***	-2.293***	
	(0.0210)	(0.0515)	
Tuesday	0.194***	3.790***	
	(0.0445)	(0.1450)	
Wednesday	0.658***	1.968***	
	(0.0644)	(0.1070)	
Thursday	0.953***	5.560***	
	(0.0470)	(0.1610)	
Friday	0.798***	3.865***	
	(0.0265)	(0.0945)	
Saturday	0.177***	1.926***	
	(0.0146)	(0.0480)	
Constant	3.217***	17.37***	1.233***
	(0.2000)	(0.3350)	(0.2070)
Obs.	1757884	1757884	29207
R-squared	0.951	0.786	0.899
IDs	377	511	600

Notes: Column (1) reports the estimate for equation (2) for the pre-2010 subsample, which corresponds to the long-run relationship between retail gasoline prices and crude oil price; Column (2) reports the estimate for equation (2) for the post-2010 subsample, and column (3) the estimates for equation (3) when using weekly aggregated data spanning the entire sample. Robust standard errors in parentheses.

(*** $p<0.01$, ** $p<0.05$, * $p<0.1$)

Table 10: Testing Asymmetry in Contemporaneous Response, Pre, Post, and Weekly

	H_0: $ß_i = 0$		H_0: $ß_i^+ = ß_i^-$	
Relationship	P-Value (Input$^+$)	P-Value (Input$^-$)	Statistic	P-Value
Daily (Full Sample)	0.2680***	0.2676***	0.000	0.969
Daily (Pre 2010)	0.371***	0.265***	120.24	0.000***
Daily (Post 2010)	0.1479***	0.2098***	13.04	0.003***
Weekly	0.710***	0.814***	216.09	0.000***

Note: This table reports the results from testing for asymmetry in the contemporaneous response in equations (4)-(6). The first row shows the results for the full sample, repeated from table 7. The second and third row show the results when using the pre-2010 and post-2010 subsamples, respectively. The third row contains the results when using data aggregated to the weekly level.

(*** $p<0.01$, ** $p<0.05$, * $p<0.1$)

Online Appendix (not for publication):

Table A1: All Error Correction Model Estimates (From Table 6)

Wholesale on Pump		**Oil on Wholesale**		**Oil on Pump**	
	(1) FE		**(2) FE**		**(3) FE**
ΔP_1^+	-0.445***	ΔTGP_1^+	0.00304	ΔP_1^+	-0.392***
	(0.00781)		(0.0297)		(0.00695)
ΔP_1^-	-0.575***	ΔTGP_1^-	-0.0348	ΔP_1^-	-0.526***
	(0.0214)		(0.0321)		(0.0234)
ΔP_2^+	-0.400***	ΔTGP_2^+	-0.0210	ΔP_2^+	-0.332***
	(0.00749)		(0.0302)		(0.00601)
ΔP_2^-	-0.351***	ΔTGP_2^-	-0.0447	ΔP_2^-	-0.269***
	(0.00923)		(0.0341)		(0.00849)
ΔP_3^+	-0.391***	ΔTGP_3^+	0.135***	ΔP_3^+	-0.308***
	(0.00765)		(0.0253)		(0.00567)
ΔP_3^-	-0.361***	ΔTGP_3^-	0.00234	ΔP_3^-	-0.267***
	(0.00726)		(0.119)		(0.00570)
ΔP_4^+	-0.393***	ΔTGP_4^+	0.113**	ΔP_4^+	-0.297***
	(0.00756)		(0.0306)		(0.00512)
ΔP_4^-	-0.365***	ΔTGP_4^-	0.126***	ΔP_4^-	-0.255***
	(0.00765)		(0.0275)		(0.00575)
ΔP_5^+	-0.408***	ΔTGP_5^+	0.0360**	ΔP_5^+	-0.301***
	(0.00788)		(0.0101)		(0.00509)
ΔP_5^-	-0.360***	ΔTGP_5^-	0.0433	ΔP_5^-	-0.236***
	(0.00861)		(0.0307)		(0.00660)
ΔP_6^+	-0.418***	ΔTGP_6^+	0.0254	ΔP_6^+	-0.293***
	(0.00772)		(0.0131)		(0.00451)
ΔP_6^-	-0.296***	ΔTGP_6^-	0.0321	ΔP_6^-	-0.160***
	(0.00856)		(0.0246)		(0.00623)
ΔP_7^+	0.0713***	ΔTGP_7^+	0.0936***	ΔP_7^+	0.216***
	(0.00866)		(0.0210)		(0.00510)
ΔP_7^-	-0.0851***	ΔTGP_7^-	0.162***	ΔP_7^-	0.0631***
	(0.0119)		(0.0352)		(0.00951)
ΔP_8^+	-0.176***	ΔTGP_8^+	-0.0454**	ΔP_8^+	-0.0253***
	(0.00715)		(0.0143)		(0.00463)
ΔP_8^-	-0.111***	ΔTGP_8^-	-0.0186	ΔP_8^-	0.0320***
	(0.0101)		(0.0121)		(0.0108)
ΔP_9^+	-0.226***	ΔTGP_9^+	-0.0388*	ΔP_9^+	-0.0912***
	(0.00631)		(0.0153)		(0.00345)
ΔP_9^-	-0.222***	ΔTGP_9^-	-0.0197	ΔP_9^-	-0.0991***
	(0.00605)		(0.0144)		(0.00492)
ΔP_{10}^+	-0.233***	ΔTGP_{10}^+	-0.0713**	ΔP_{10}^+	-0.111***
	(0.00587)		(0.0210)		(0.00317)
ΔP_{10}^-	-0.227***	ΔTGP_{10}^-	-0.00464	ΔP_{10}^-	-0.119***
	(0.00645)		(0.0455)		(0.00366)
ΔP_{11}^+	-0.228***	ΔTGP_{11}^+	0.0222	ΔP_{11}^+	-0.118***
	(0.00576)		(0.0160)		(0.00333)
ΔP_{11}^-	-0.225***	ΔTGP_{11}^-	-0.0591**	ΔP_{11}^-	-0.131***
	(0.00625)		(0.0175)		(0.00402)

ΔP_{12}^{+}	-0.213***	ΔTGP_{12}^{+}	0.00810	ΔP_{12}^{+}	-0.115***
	(0.00511)		(0.00897)		(0.00295)
ΔP_{12}^{-}	-0.190***	ΔTGP_{12}^{-}	-0.0126	ΔP_{12}^{-}	-0.113***
	(0.00649)		(0.0168)		(0.00447)
ΔP_{13}^{+}	-0.209***	ΔTGP_{13}^{+}	-0.00164	ΔP_{13}^{+}	-0.124***
	(0.00531)		(0.00624)		(0.00378)
ΔP_{13}^{-}	-0.114***	ΔTGP_{13}^{-}	-0.00617	ΔP_{13}^{-}	-0.0521***
	(0.00612)		(0.0197)		(0.00469)
ΔP_{14}^{+}	0.281***	ΔTGP_{14}^{+}	0.0160	ΔP_{14}^{+}	0.349***
	(0.00517)		(0.0142)		(0.00463)
ΔP_{14}^{-}	0.0371***	ΔTGP_{14}^{-}	0.101***	ΔP_{14}^{-}	0.0785***
	(0.00805)		(0.00898)		(0.00725)
ΔTGP_{1}^{+}	0.268***	ΔOil_{1}^{+}	0.00373	ΔOil_{1}^{+}	0.0411***
	(0.00681)		(0.00481)		(0.00455)
ΔTGP_{1}^{-}	0.268***	ΔOil_{1}^{-}	-0.00701	ΔOil_{1}^{-}	0.0266***
	(0.00847)		(0.00393)		(0.00432)
ΔTGP_{2}^{+}	0.250***	ΔOil_{2}^{+}	0.0223*	ΔOil_{2}^{+}	-0.0735***
	(0.00765)		(0.0104)		(0.00440)
ΔTGP_{2}^{-}	0.220***	ΔOil_{2}^{-}	-0.00360	ΔOil_{2}^{-}	0.0182***
	(0.00748)		(0.00549)		(0.00424)
ΔTGP_{3}^{+}	0.223***	ΔOil_{3}^{+}	0.0381**	ΔOil_{3}^{+}	-0.0489***
	(0.00657)		(0.0135)		(0.00418)
ΔTGP_{3}^{-}	0.221***	ΔOil_{3}^{-}	0.0308***	ΔOil_{3}^{-}	0.0117***
	(0.00839)		(0.00373)		(0.00446)
ΔTGP_{4}^{+}	0.223***	ΔOil_{4}^{+}	0.0282**	ΔOil_{4}^{+}	-0.0544***
	(0.00749)		(0.00886)		(0.00480)
ΔTGP_{4}^{-}	0.261***	ΔOil_{4}^{-}	0.0537***	ΔOil_{4}^{-}	0.0286***
	(0.00756)		(0.00942)		(0.00382)
ΔTGP_{5}^{+}	0.258***	ΔOil_{5}^{+}	0.0536***	ΔOil_{5}^{+}	0.0241***
	(0.00693)		(0.00372)		(0.00472)
ΔTGP_{5}^{-}	0.191***	ΔOil_{5}^{-}	0.0526***	ΔOil_{5}^{-}	0.00220
	(0.00676)		(0.00755)		(0.00434)
ΔTGP_{6}^{+}	0.328***	ΔOil_{6}^{+}	0.118***	ΔOil_{6}^{+}	0.0319***
	(0.00755)		(0.00664)		(0.00530)
ΔTGP_{6}^{-}	0.240***	ΔOil_{6}^{-}	0.0794***	ΔOil_{6}^{-}	0.0444***
	(0.00685)		(0.00580)		(0.00511)
ΔTGP_{7}^{+}	0.267***	ΔOil_{7}^{+}	0.141***	ΔOil_{7}^{+}	0.0841***
	(0.00792)		(0.00694)		(0.00637)
ΔTGP_{7}^{-}	0.210***	ΔOil_{7}^{-}	0.141***	ΔOil_{7}^{-}	0.0334***
	(0.00755)		(0.0109)		(0.00523)
ΔTGP_{8}^{+}	0.0682***	ΔOil_{8}^{+}	0.139***	ΔOil_{8}^{+}	0.101***
	(0.00674)		(0.0152)		(0.00495)
ΔTGP_{8}^{-}	0.361***	ΔOil_{8}^{-}	0.121***	ΔOil_{8}^{-}	0.125***
	(0.00789)		(0.0152)		(0.00504)
ΔTGP_{9}^{+}	0.195***	ΔOil_{9}^{+}	0.0620***	ΔOil_{9}^{+}	0.0550***
	(0.00714)		(0.0117)		(0.00487)
ΔTGP_{9}^{-}	0.315***	ΔOil_{9}^{-}	0.0984***	ΔOil_{9}^{-}	0.197***
	(0.00805)		(0.0131)		(0.00560)
ΔTGP_{10}^{+}	0.204***	ΔOil_{10}^{+}	0.0345***	ΔOil_{10}^{+}	0.138***
	(0.00815)		(0.00481)		(0.00407)
ΔTGP_{10}^{-}	0.254***	ΔOil_{10}^{-}	0.0894***	ΔOil_{10}^{-}	0.187***
	(0.00880)		(0.0201)		(0.00550)

ΔTGP_{11}^{+}	0.258***	ΔOil_{11}^{+}	0.0478***	ΔOil_{11}^{+}	0.143***
	(0.00818)		(0.0110)		(0.00414)
ΔTGP_{11}^{-}	0.222***	ΔOil_{11}^{-}	0.0297**	ΔOil_{11}^{-}	0.199***
	(0.00938)		(0.0102)		(0.00553)
ΔTGP_{12}^{+}	0.212***	ΔOil_{12}^{+}	0.0326**	ΔOil_{12}^{+}	0.238***
	(0.00876)		(0.0119)		(0.00615)
ΔTGP_{12}^{-}	0.282***	ΔOil_{12}^{-}	0.0418***	ΔOil_{12}^{-}	0.160***
	(0.0102)		(0.00936)		(0.00508)
ΔTGP_{13}^{+}	0.199***	ΔOil_{13}^{+}	0.0396***	ΔOil_{13}^{+}	0.202***
	(0.00952)		(0.00798)		(0.00667)
ΔTGP_{13}^{-}	0.180***	ΔOil_{13}^{-}	0.0182	ΔOil_{13}^{-}	0.186***
	(0.00862)		(0.0233)		(0.00490)
ΔTGP_{14}^{+}	0.110***	ΔOil_{14}^{+}	0.0142	ΔOil_{14}^{+}	0.177***
	(0.00607)		(0.0117)		(0.00566)
ΔTGP_{14}^{-}	0.255***	ΔOil_{14}^{-}	0.0129	ΔOil_{14}^{-}	0.200***
	(0.00808)		(0.0105)		(0.00632)
Z^{+}	-0.00741***	Z^{+}	-0.00559**	Z^{+}	-0.0224***
	(0.00186)		(0.00168)		(0.00169)
Z^{-}	-0.101***	Z^{-}	-0.0141***	Z^{-}	-0.0524***
	(0.00417)		(0.00316)		(0.00150)
Constant	-0.264***	Constant	-0.0219	Constant	-0.163***
	(0.0212)		(0.0155)		(0.0158)
Obs.	1,741,936	Obs.	29,138	Obs.	1,741,936
R^2	0.751	R^2	0.236	R^2	0.735
IDs	597	IDs	6	IDs	597

Note: Column (1) reports the estimate for equation (4), which corresponds to the ECM for retail gasoline prices on crude oil price; column (2) the relationship between wholesale gasoline and retail gasoline (model 5), and column (3) the relationship between crude oil and wholesale gasoline (model 6). Robust standard errors in parentheses.

(*** p<0.01, ** p<0.05, * p<0.1)

Table A2: Nearest Neighbor, Long-Run Model

	Base Model	Uni-Dummy	Multi-Dummy
	(1)	(2)	(3)
Wholesale	1.051***	1.066***	1.067***
	(0.0017)	(0.0021)	(0.0022)
# of Nearby Firms		-0.667***	
		(0.0641)	
1 Nearby Firm			-4.173***
			(0.4330)
2 Nearby Firm			-4.212***
			(0.3440)
3 Nearby Firm			-4.835***
			(0.3670)
4 Nearby Firm			-4.540***
			(0.4270)
5 Nearby Firm			-5.088***
			(0.5040)
6 Nearby Firm			-4.659***
			(0.5410)
7 Nearby Firm			-4.168***
			(0.8150)
8 Nearby Firm			-3.546***
			(0.9480)
9 Nearby Firm			-2.480**
			(1.0780)
10+ Nearby Firm			0.0162
			(1.4550)
Summer	0.566***	0.641***	0.645***
	(0.0250)	(0.0254)	(0.0252)
Monday	-1.332***	-1.332***	-1.331***
	(0.0367)	(0.0367)	(0.0367)
Tuesday	2.203***	2.203***	2.203***
	(0.0900)	(0.0900)	(0.0900)
Wednesday	1.378***	1.378***	1.378***
	(0.0721)	(0.0721)	(0.0720)
Thursday	3.522***	3.521***	3.521***
	(0.1060)	(0.1060)	(0.1060)
Friday	2.510***	2.506***	2.505***
	(0.0645)	(0.0645)	(0.0644)
Saturday	1.149***	1.146***	1.144***
	(0.0322)	(0.0322)	(0.0321)

Constant	-0.114	0.0137	1.579***
	(0.2080)	(0.2330)	(0.2710)
Obs.	1757884	1757884	1757884
R-squared	0.883	0.884	0.887
IDs	600	600	600

Note: Column (1) reports the estimates from the base model, repeated from table 5. Column (2) reports the estimates from equation (2), the long-run relationship between wholesale and retail gasoline prices, with an included dummy variable for number of nearby firms. Column (3) reports the estimates from equation (2) with individual dummy variables for each potential number of nearby firms. Stations must be within 2km of each other to be considered a nearby firm. Robust standard errors in parentheses.

(*** $p<0.01$, ** $p<0.05$, * $p<0.1$)

Table A3: Nearest Neighbor, Dynamic Model

Table A3: Nearest Neighbor, Dynamics Model

	Base Model (1)	Uni-Dummy (2)	Multi-Dummy (3)
ΔP_1^+	-0.445***	-0.444***	-0.444***
	(0.00781)	(0.00779)	(0.00779)
ΔP_1^-	-0.575***	-0.400***	-0.399***
	(0.0214)	(0.00748)	(0.00748)
ΔP_2^+	-0.400***	-0.391***	-0.390***
	(0.00749)	(0.00764)	(0.00764)
ΔP_2^-	-0.351***	-0.393***	-0.392***
	(0.00923)	(0.00754)	(0.00755)
ΔP_3^+	-0.391***	-0.408***	-0.408***
	(0.00765)	(0.00787)	(0.00787)
ΔP_3^-	-0.361***	-0.418***	-0.418***
	(0.00726)	(0.00771)	(0.00771)
ΔP_4^+	-0.393***	0.0713***	0.0714***
	(0.00756)	(0.00866)	(0.00866)
ΔP_4^-	-0.365***	-0.176***	-0.176***
	(0.00765)	(0.00714)	(0.00715)
ΔP_5^+	-0.408***	-0.226***	-0.226***
	(0.00788)	(0.00631)	(0.00631)
ΔP_5^-	-0.360***	-0.233***	-0.233***
	(0.00861)	(0.00586)	(0.00587)
ΔP_6^+	-0.418***	-0.228***	-0.228***
	(0.00772)	(0.00576)	(0.00576)
ΔP_6^-	-0.296***	-0.213***	-0.213***
	(0.00856)	(0.00511)	(0.00511)
ΔP_7^+	0.0713***	-0.209***	-0.209***
	(0.00866)	(0.00531)	(0.00531)
ΔP_7^-	-0.0851***	0.281***	0.281***
	(0.0119)	(0.00517)	(0.00517)
ΔP_8^+	-0.176***	-0.575***	-0.574***
	(0.00715)	(0.0214)	(0.0214)
ΔP_8^-	-0.111***	-0.351***	-0.351***
	(0.0101)	(0.00922)	(0.00922)
ΔP_9^+	-0.226***	-0.361***	-0.361***
	(0.00631)	(0.00725)	(0.00725)
ΔP_9^-	-0.222***	-0.364***	-0.364***
	(0.00605)	(0.00764)	(0.00764)
ΔP_{10}^+	-0.233***	-0.359***	-0.359***
	(0.00587)	(0.00861)	(0.00861)
ΔP_{10}^-	-0.227***	-0.296***	-0.296***
	(0.00645)	(0.00855)	(0.00855)

ΔP_{11}^{+}	-0.228***	-0.0850***	-0.0846***
	(0.00576)	(0.0119)	(0.0119)
ΔP_{11}^{-}	-0.225***	-0.111***	-0.110***
	(0.00625)	(0.0101)	(0.0101)
ΔP_{12}^{+}	-0.213***	-0.222***	-0.222***
	(0.00511)	(0.00605)	(0.00605)
ΔP_{12}^{-}	-0.190***	-0.227***	-0.226***
	(0.00649)	(0.00645)	(0.00645)
ΔP_{13}^{+}	-0.209***	-0.225***	-0.225***
	(0.00531)	(0.00625)	(0.00625)
ΔP_{13}^{-}	-0.114***	-0.190***	-0.190***
	(0.00612)	(0.00649)	(0.00649)
ΔP_{14}^{+}	0.281***	-0.114***	-0.114***
	(0.00517)	(0.00611)	(0.00612)
ΔP_{14}^{-}	0.0371***	0.0372***	0.0374***
	(0.00805)	(0.00805)	(0.00806)
ΔTGP_{1}^{+}	0.268***	0.268***	0.266***
	(0.00681)	(0.00681)	(0.00681)
ΔTGP_{1}^{-}	0.268***	0.250***	0.248***
	(0.00847)	(0.00764)	(0.00765)
ΔTGP_{2}^{+}	0.250***	0.223***	0.221***
	(0.00765)	(0.00654)	(0.00655)
ΔTGP_{2}^{-}	0.220***	0.223***	0.222***
	(0.00748)	(0.00748)	(0.00748)
ΔTGP_{3}^{+}	0.223***	0.258***	0.257***
	(0.00657)	(0.00693)	(0.00693)
ΔTGP_{3}^{-}	0.221***	0.328***	0.327***
	(0.00839)	(0.00755)	(0.00756)
ΔTGP_{4}^{+}	0.223***	0.267***	0.266***
	(0.00749)	(0.00792)	(0.00792)
ΔTGP_{4}^{-}	0.261***	0.0679***	0.0664***
	(0.00756)	(0.00673)	(0.00674)
ΔTGP_{5}^{+}	0.258***	0.195***	0.194***
	(0.00693)	(0.00713)	(0.00715)
ΔTGP_{5}^{-}	0.191***	0.203***	0.202***
	(0.00676)	(0.00813)	(0.00814)
ΔTGP_{6}^{+}	0.328***	0.258***	0.257***
	(0.00755)	(0.00817)	(0.00818)
ΔTGP_{6}^{-}	0.240***	0.212***	0.211***
	(0.00685)	(0.00875)	(0.00875)
ΔTGP_{7}^{+}	0.267***	0.199***	0.199***
	(0.00792)	(0.00951)	(0.00951)
ΔTGP_{7}^{-}	0.210***	0.109***	0.108***
	(0.00755)	(0.00606)	(0.00608)
ΔTGP_{8}^{+}	0.0682***	0.268***	0.269***
	(0.00674)	(0.00848)	(0.00848)

ΔTGP_8^-	0.361***	0.220***	0.220***
	(0.00789)	(0.00746)	(0.00747)
ΔTGP_9^+	0.195***	0.221***	0.220***
	(0.00714)	(0.00836)	(0.00838)
ΔTGP_9^-	0.315***	0.260***	0.259***
	(0.00805)	(0.00754)	(0.00754)
ΔTGP_{10}^+	0.204***	0.191***	0.190***
	(0.00815)	(0.00674)	(0.00675)
ΔTGP_{10}^-	0.254***	0.239***	0.239***
	(0.00880)	(0.00684)	(0.00686)
ΔTGP_{11}^+	0.258***	0.210***	0.210***
	(0.00818)	(0.00755)	(0.00755)
ΔTGP_{11}^-	0.222***	0.361***	0.361***
	(0.00938)	(0.00789)	(0.00789)
ΔTGP_{12}^+	0.212***	0.315***	0.315***
	(0.00876)	(0.00805)	(0.00806)
ΔTGP_{12}^-	0.282***	0.254***	0.254***
	(0.0102)	(0.00880)	(0.00882)
ΔTGP_{13}^+	0.199***	0.221***	0.221***
	(0.00952)	(0.00936)	(0.00939)
ΔTGP_{13}^-	0.180***	0.281***	0.281***
	(0.00862)	(0.0102)	(0.0102)
ΔTGP_{14}^+	0.110***	0.179***	0.179***
	(0.00607)	(0.00860)	(0.00861)
ΔTGP_{14}^-	0.255***	0.255***	0.255***
	(0.00808)	(0.00807)	(0.00808)
Z^+	-0.00741***	-0.00796***	-0.00914***
	(0.00186)	(0.00191)	(0.00193)
Z^-	-0.101***	-0.102***	-0.102***
	(0.00417)	(0.00418)	(0.00417)
1 Nearby firm			-0.120***
			(0.0177)
2 Nearby Firms			-0.125***
			(0.0153)
3 Nearby Firms			-0.138***
			(0.0166)
4 Nearby Firms			-0.109***
			(0.0188)
5 Nearby Firms			-0.124***
			(0.0210)
6 Nearby Firms			-0.0979***
			(0.0227)
7 Nearby Firms			-0.0966***
			(0.0288)
8 Nearby Firms			-0.0499
			(0.0328)

9 Nearby Firms			-0.0210
			(0.0426)
10 Nearby Firms			0.0491
			(0.0643)
11 Nearby Firms			0.125**
			(0.0531)
12 Nearby Firms			0.243***
			(0.0790)
13 Nearby Firms			0.290***
			(0.0535)
# of Nearby Firms		-0.0131***	
		(0.00223)	
Constant	-0.264***	-0.224***	-0.158***
	(0.0212)	(0.0237)	(0.0252)
Obs.	1,741,936	1,741,936	1,741,936
R^2	0.751	0.751	0.751
IDs	597	597	597

Note: Column (1) reports the estimate for equation (4), which corresponds to the ECM for retail gasoline prices on crude oil price, repeated from Table A1; column (2) includes the multi-variate dummy variable for nearby firms, and column (3) includes individual dummy variables for each number of nearby firms. Robust standard errors in parentheses. (*** p<0.01, ** p<0.05, * p<0.1)

Table A4: Highway Effects, Long-Run

	Base Model	Highway	Highway & Nearby
	(1)	(2)	(3)
Wholesale	1.051***	1.051***	1.066***
	(0.0017)	(0.0017)	(0.0021)
Summer	0.566***	0.566***	0.641***
	(0.0250)	(0.0250)	(0.0254)
Monday	-1.332***	-1.332***	-1.332***
	(0.0367)	(0.0367)	(0.0367)
Tuesday	2.203***	2.203***	2.203***
	(0.0900)	(0.0900)	(0.0900)
Wednesday	1.378***	1.378***	1.378***
	(0.0721)	(0.0721)	(0.0721)
Thursday	3.522***	3.522***	3.521***
	(0.1060)	(0.1060)	(0.1060)
Friday	2.510***	2.510***	2.506***
	(0.0645)	(0.0645)	(0.0645)
Saturday	1.149***	1.149***	1.146***
	(0.0322)	(0.0322)	(0.0322)
# of Nearby Firms			-0.668***
			(0.0640)
Highway		-0.151	-0.166
		(0.3850)	(0.3360)
Constant	(0.1140)	1.799***	1.391***
	(0.2080)	(0.2930)	(0.2860)
Observations	1757884	1757884	1757884
R-squared	0.8830		
Number of id	600	600	600

Note: Column (1) reports the estimates from the base model, repeated from table 5. Column (2) reports the estimates from equation (2), the long-run relationship between wholesale and retail gasoline prices, with an included dummy variable for whether or not the station is near a major highway. Column (3) reports the estimates from equation (2) accounting for both highways and nearby stations. Stations must be within 2km of each other to be considered a nearby firm. Station must be in the same postal code as a highway to be considered near a highway. Robust standard errors in parentheses.

(*** p<0.01, ** p<0.05, * p<0.1)

Table A5: Full Error Correction Model (Mean Group)

Wholesale on Pump		Oil on Wholesale		Oil on Pump	
	(1)		(2)		(3)
ΔP_1^+	-0.363***	ΔTGP_1^+	0.00699	ΔP_1^+	-0.315***
	(0.0113)		(0.0353)		(0.00862)
ΔP_1^-	-0.305***	ΔTGP_1^-	0.00523	ΔP_1^-	-0.252***
	(0.0126)		(0.0727)		(0.0118)
ΔP_2^+	-0.313***	ΔTGP_2^+	-0.00459	ΔP_2^+	-0.246***
	(0.00908)		(0.0338)		(0.00919)
ΔP_2^-	-0.259***	ΔTGP_2^-	-0.0549	ΔP_2^-	-0.165***
	(0.00973)		(0.0433)		(0.00940)
ΔP_3^+	-0.325***	ΔTGP_3^+	0.108***	ΔP_3^+	-0.241***
	(0.00952)		(0.0317)		(0.00811)
ΔP_3^-	-0.268***	ΔTGP_3^-	0.0490	ΔP_3^-	-0.157***
	(0.00850)		(0.0811)		(0.0109)
ΔP_4^+	-0.321***	ΔTGP_4^+	0.116***	ΔP_4^+	-0.225***
	(0.00818)		(0.0312)		(0.00778)
ΔP_4^-	-0.300***	ΔTGP_4^-	0.119***	ΔP_4^-	-0.173***
	(0.00781)		(0.0413)		(0.00783)
ΔP_5^+	-0.326***	ΔTGP_5^+	0.0566***	ΔP_5^+	-0.197***
	(0.00850)		(0.0133)		(0.00841)
ΔP_5^-	-0.297***	ΔTGP_5^-	0.0614**	ΔP_5^-	-0.155***
	(0.00874)		(0.0274)		(0.00787)
ΔP_6^+	-0.358***	ΔTGP_6^+	0.0437***	ΔP_6^+	-0.237***
	(0.00800)		(0.0134)		(0.00762)
ΔP_6^-	-0.217***	ΔTGP_6^-	0.0460*	ΔP_6^-	-0.0821***
	(0.00994)		(0.0279)		(0.00763)
ΔP_7^+	0.121***	ΔTGP_7^+	0.0970***	ΔP_7^+	0.262***
	(0.0118)		(0.0204)		(0.0115)
ΔP_7^-	-0.0475***	ΔTGP_7^-	0.123***	ΔP_7^-	0.107***
	(0.00918)		(0.0406)		(0.00787)
ΔP_8^+	-0.0888***	ΔTGP_8^+	-0.0478***	ΔP_8^+	0.0302***
	(0.00892)		(0.0170)		(0.00742)
ΔP_8^-	-0.104***	ΔTGP_8^-	-0.0142	ΔP_8^-	0.0425***
	(0.00847)		(0.0126)		(0.00887)
ΔP_9^+	-0.148***	ΔTGP_9^+	-0.0433***	ΔP_9^+	-0.0632***
	(0.00719)		(0.0116)		(0.00614)
ΔP_9^-	-0.139***	ΔTGP_9^-	-0.0236	ΔP_9^-	-0.0272***
	(0.00777)		(0.0167)		(0.00757)
ΔP_{10}^+	-0.165***	ΔTGP_{10}^+	-0.0608**	ΔP_{10}^+	-0.0796***
	(0.00736)		(0.0284)		(0.00582)
ΔP_{10}^-	-0.122***	ΔTGP_{10}^-	-0.0167	ΔP_{10}^-	-0.0578***
	(0.00779)		(0.0298)		(0.00647)
ΔP_{11}^+	-0.165***	ΔTGP_{11}^+	0.00977	ΔP_{11}^+	-0.0828***
	(0.00636)		(0.0142)		(0.00554)
ΔP_{11}^-	-0.132***	ΔTGP_{11}^-	-0.0555**	ΔP_{11}^-	-0.0500***
	(0.00975)		(0.0230)		(0.00618)
ΔP_{12}^+	-0.169***	ΔTGP_{12}^+	0.000612	ΔP_{12}^+	-0.109***
	(0.00652)		(0.0132)		(0.00619)

ΔP_{12}^-	-0.116***	ΔTGP_{12}^-	-0.0186	ΔP_{12}^-	-0.0550***
	(0.00680)		(0.0167)		(0.00640)
ΔP_{13}^+	-0.143***	ΔTGP_{13}^+	-0.000270	ΔP_{13}^+	-0.0777***
	(0.00640)		(0.00847)		(0.00562)
ΔP_{13}^-	-0.0528***	ΔTGP_{13}^-	0.00979	ΔP_{13}^-	-0.0189***
	(0.00640)		(0.0171)		(0.00597)
ΔP_{14}^+	0.176***	ΔTGP_{14}^+	0.0199	ΔP_{14}^+	0.216***
	(0.00641)		(0.0123)		(0.00727)
ΔP_{14}^-	0.0110*	ΔTGP_{14}^-	0.0956***	ΔP_{14}^-	0.0590***
	(0.00614)		(0.0164)		(0.00588)
ΔTGP_{1}^+	0.0726	ΔOil_{1}^+	0.00608	ΔOil_{1}^+	0.0988***
	(0.0542)		(0.00633)		(0.0205)
ΔTGP_{1}^-	0.0236	ΔOil_{1}^-	-0.00715	ΔOil_{1}^-	-0.00295
	(0.0335)		(0.00512)		(0.0131)
ΔTGP_{2}^+	0.0543	ΔOil_{2}^+	0.0254***	ΔOil_{2}^+	-0.210***
	(0.0478)		(0.00886)		(0.0194)
ΔTGP_{2}^-	0.319***	ΔOil_{2}^-	-0.00433	ΔOil_{2}^-	-0.0230
	(0.0359)		(0.00603)		(0.0153)
ΔTGP_{3}^+	0.0344	ΔOil_{3}^+	0.0407***	ΔOil_{3}^+	-0.125***
	(0.0467)		(0.0117)		(0.0187)
ΔTGP_{3}^-	-0.121***	ΔOil_{3}^-	0.0301***	ΔOil_{3}^-	-0.0425***
	(0.0336)		(0.00471)		(0.0134)
ΔTGP_{4}^+	0.211***	ΔOil_{4}^+	0.0288***	ΔOil_{4}^+	-0.0560**
	(0.0575)		(0.00857)		(0.0219)
ΔTGP_{4}^-	0.271***	ΔOil_{4}^-	0.0485***	ΔOil_{4}^-	-0.0918***
	(0.0310)		(0.0103)		(0.0147)
ΔTGP_{5}^+	0.0724	ΔOil_{5}^+	0.0550***	ΔOil_{5}^+	0.00870
	(0.0550)		(0.00392)		(0.0222)
ΔTGP_{5}^-	-0.0807**	ΔOil_{5}^-	0.0512***	ΔOil_{5}^-	-0.160***
	(0.0317)		(0.00682)		(0.0159)
ΔTGP_{6}^+	0.0744	ΔOil_{6}^+	0.115***	ΔOil_{6}^+	-0.0297
	(0.0672)		(0.00569)		(0.0218)
ΔTGP_{6}^-	0.355***	ΔOil_{6}^-	0.0764***	ΔOil_{6}^-	0.0114
	(0.0294)		(0.00649)		(0.0157)
ΔTGP_{7}^+	-0.0386	ΔOil_{7}^+	0.136***	ΔOil_{7}^+	0.0261
	(0.0654)		(0.00753)		(0.0198)
ΔTGP_{7}^-	0.0791***	ΔOil_{7}^-	0.136***	ΔOil_{7}^-	-0.145***
	(0.0265)		(0.00948)		(0.0180)
ΔTGP_{8}^+	-0.145**	ΔOil_{8}^+	0.133***	ΔOil_{8}^+	-0.0899***
	(0.0570)		(0.0158)		(0.0270)
ΔTGP_{8}^-	0.334***	ΔOil_{8}^-	0.112***	ΔOil_{8}^-	0.00954
	(0.0300)		(0.0165)		(0.0171)
ΔTGP_{9}^+	-0.0899*	ΔOil_{9}^+	0.0632***	ΔOil_{9}^+	-0.253***
	(0.0516)		(0.00922)		(0.0272)
ΔTGP_{9}^-	0.500***	ΔOil_{9}^-	0.0898***	ΔOil_{9}^-	0.0737***
	(0.0353)		(0.0110)		(0.0144)
ΔTGP_{10}^+	0.242***	ΔOil_{10}^+	0.0324***	ΔOil_{10}^+	-0.0775***
	(0.0541)		(0.00450)		(0.0219)
ΔTGP_{10}^-	-0.110**	ΔOil_{10}^-	0.0780***	ΔOil_{10}^-	0.0948***
	(0.0451)		(0.0179)		(0.0143)
ΔTGP_{11}^+	0.222***	ΔOil_{11}^+	0.0431***	ΔOil_{11}^+	-0.114***
	(0.0552)		(0.0121)		(0.0308)

ΔTGP_{11}^{-}	0.192***	ΔOil_{11}^{-}	0.0282***	ΔOil_{11}^{-}	0.107***
	(0.0343)		(0.00968)		(0.0137)
ΔTGP_{12}^{+}	0.239***	ΔOil_{12}^{+}	0.0286**	ΔOil_{12}^{+}	0.123***
	(0.0489)		(0.0122)		(0.0260)
ΔTGP_{12}^{-}	-0.0270	ΔOil_{12}^{-}	0.0364***	ΔOil_{12}^{-}	0.108***
	(0.0388)		(0.00901)		(0.0148)
ΔTGP_{13}^{+}	0.0545	ΔOil_{13}^{+}	0.0351***	ΔOil_{13}^{+}	0.0318
	(0.0414)		(0.00962)		(0.0207)
ΔTGP_{13}^{-}	0.303***	ΔOil_{13}^{-}	0.0167	ΔOil_{13}^{-}	0.152***
	(0.0334)		(0.0204)		(0.0136)
ΔTGP_{14}^{+}	-0.201***	ΔOil_{14}^{+}	0.00311	ΔOil_{14}^{+}	0.111***
	(0.0552)		(0.0122)		(0.0176)
ΔTGP_{14}^{-}	0.0672**	ΔOil_{14}^{-}	0.0112	ΔOil_{14}^{-}	0.0526***
	(0.0316)		(0.0129)		(0.0177)
Z^{+}	-0.124***	Z^{+}	-0.00591***	Z^{+}	-0.126***
	(0.0109)		(0.00183)		(0.00983)
Z^{-}	-0.245***	Z^{-}	-0.0126***	Z^{-}	-0.576**
	(0.0187)		(0.00241)		(0.284)
Constant	0.943***	Constant	-0.0253	Constant	1.715***
	(0.105)		(0.0212)		(0.163)
Obs.	1,741,628	Obs.	29,138	Obs.	1,741,628
IDs	588	IDs	6	IDs	588

Note: This table shows the results from the dynamic model when using Pesaran and Smith's Mean Group (MG) analysis. Column (1) reports the estimate for equation (4), which corresponds to the ECM for retail gasoline prices on crude oil price; column (2) the relationship between wholesale gasoline and retail gasoline (model 5), and column (3) the relationship between crude oil and wholesale gasoline (model 6). Robust standard errors in parentheses.

(*** $p<0.01$, ** $p<0.05$, * $p<0.1$)

Table A6: Testing Asymmetry in Contemporaneous Response, Mean Group

	H_0: ß$_i$ = 0		H_0: ß$_i^+$ = ß$_i^-$	
Relationship	P-Value (Input$^+$)	P-Value (Input$^-$)	Statistic	P-Value
Oil to Pump (ß$_{c1}$)	0.0987***	-0.0029	13.41	0.0002***
Oil to Wholesale (ß$_{c1}$)	0.006	-0.0071	1.44	0.2298
Wholesale to Pump (ß$_{w1}$)	0.0725	0.0236	0.48	0.4878

Note: This table reports the results from testing for asymmetry in the contemporaneous response in equations (4)-(6) using Pesaran and Smith Mean Group analysis.
(*** p<0.01, ** p<0.05, * p<0.1)

Table A7: Testing Asymmetry in Long-Run Convergence Rates, Mean Group

	$H_0: \theta_i = 0$		$H_0: \theta_i^+ = \theta_i^-$	
Relationship	P-Value (Z^+)	P-Value (Z^-)	Statistic	P-Value
Oil to Pump	-0.1259***	-0.5762***	2.53	0.1119
Oil to Wholesale	-0.0059***	-0.0125***	3.72	0.0538*
Wholesale to Pump	-0.1242***	-0.2452**	55.48	0.0000***

Note: This table reports the results from testing for asymmetry in the long-run convergence rates in equations (4)-(6) using Pesaran and Smith Mean Group analysis.
(*** p<0.01, ** p<0.05, * p<0.1)