Regular Price Cycles in Liquefied Petroleum Gas and a Comparison with Gasoline Price Cycles*

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Abstract

This is the first paper to document regular price cycles in liquefied petroleum gas (LPG) and to compare LPG price cycles with gasoline price cycles in the same area. LPG price cycles in the Perth area of Western Australia are well characterized by the theoretical Edgeworth price cycle model. LPG price cycles are much longer and more asymmetric than gasoline price cycles, which is consistent with Noel's (2008) prediction that Edgeworth cycles are longer and more asymmetric when aggregate demand is more elastic. The aggregate demand for LPG is much more elastic than the demand for gasoline because most LPG vehicles are dual-fuel.

Keywords

Edgeworth price cycle, liquefied petroleum gas, oligopoly pricing, price elasticity

JEL codes

D22, D43, L13, L71, Q4

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1. Introduction

Retail gasoline prices in many markets of the U.S., Canada, Australia, and some European countries move in sawtooth-shaped cycles: prices increase rapidly and then decrease slowly. These regular, frequent, and asymmetric gasoline price cycles have been the subject of public debate and government investigations. A growing economic literature has examined the mechanism underlying these gasoline price cycles and found that they are well characterized by the Edgworth price cycle equilibrium in the dynamic oligopoly model of Maskin and Tirole (1988). This literature has informed economists and antitrust authorities of the cause and welfare implications of gasoline price cycles. More generally, these studies have made important contributions to the long-standing economic literature on oligopoly pricing by carefully documenting firms' pricing strategy with high-frequency data.

This is the first paper in this literature to document regular price cycles in liquefied petroleum gas (LPG) and, importantly, to compare LPG price cycles with gasoline price cycles observed in the same geographic area. We find that the LPG price cycles in the Perth metropolitan area of Western Australia, similar to the gasoline price cycles in the same area (e.g., Wang 2009), are well characterized by the Edgeworth price cycle equilibrium. We also find that LPG price cycles are much longer and more asymmetric than gasoline price cycles. This finding is consistent with Noel's (2008) prediction that Edgeworth cycles are longer and more asymmetric when demand is more elastic.

In a comprehensive review of the gasoline price cycle literature, Noel (2011a) writes that "[a]n obvious direction for future work [in this area] is to search for and uncover additional examples of Edgeworth Price Cycles outside of retail gasoline." The markets for LPG and gasoline are very similar on the supply side, but differ significantly on the demand side. In the

Perth area, retail fuel stations that sell LPG almost always sell gasoline. As a consequence, LPG and gasoline are supplied by the same firms through the same network of retail fuel stations. The aggregate demand for LPG, however, is much more elastic than the demand for gasoline.[1] One reason is that gasoline is a substitute for LPG because most LPG-capable vehicles are gasoline-LPG dual-fuel vehicles.[2] The fact that LPG and gasoline differ in demand but not supply offers a rare opportunity to observe the impact of aggregate demand elasticity on price cycles. It would be more difficult to separate the impact of demand from the impact of supply factors if we were to compare price cycles in a non-fuel product (i.e., the market for online keyword advertising studied by Zhang 2005) with gasoline price cycles.

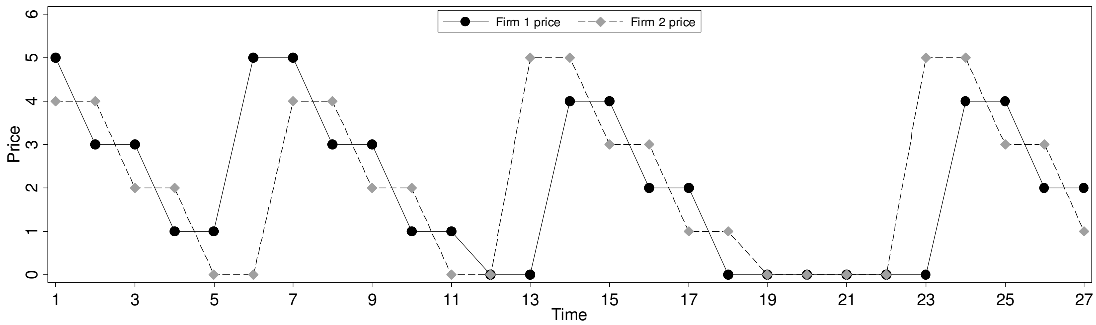
For a quick overview of our results, consider three figures. Figure 1 shows Maskin and Tirole's (1988) numerical example of an Edgeworth price cycle.[3] Figure 2 shows the brand average LPG retail prices (in Australian cents per liter before sales tax) and the wholesale price of LPG paid by one retailer in the Perth market over a period of 78 days. In both figures, firms hike prices substantially and sequentially and decrease prices gradually. These two figures, along with more detailed evidence presented in this paper, indicate that the LPG price cycles in the Perth market are well characterized by Edgeworth price cycles. Figure 3 shows the market average gasoline and LPG retail prices during a period of 5 months. LPG prices are scaled by a factor of 1.5 because a gasoline-LPG dual-fuel car that uses 1 liter of gasoline per 10 kilometers may use 1.5 liters or more of LPG per 10 kilometers. LPG price cycles are much longer and more asymmetric than gasoline price cycles, and the timing of the two cycles is quite different.

[1] We are not aware of any studies that estimate the price elasticity of demand for LPG in Australia, but Mehrara and Ahmadi (2011) find that the own price elasticity of demand for LPG as a transport fuel in Iran is -3.58, much larger than the estimated price elasticity of demand for gasoline in the literature.

[2] In contrast, about 97.5% of the vehicles during our sample period use gasoline only. For these vehicles, LPG is not a substitute for gasoline.

[3] In this example, market demand is $D(p) = 6-p$, production cost is 0 for both firms, and price must be an integer.

Figure 1: Maskin and Tirole's (1988) Edgeworth Price Cycle Example



Note: Market demand is D(p) = 6-p, production cost is 0 for both firms, and price must be an integer.

Figure 2: Daily Brand Average LPG Prices Before Sales Tax in the Perth Market, 02/20/02 – 05/08/02

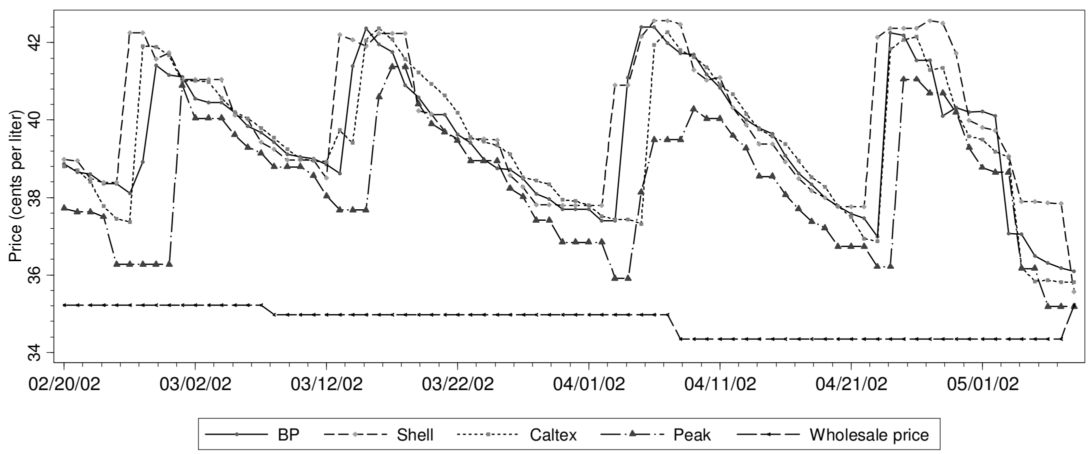
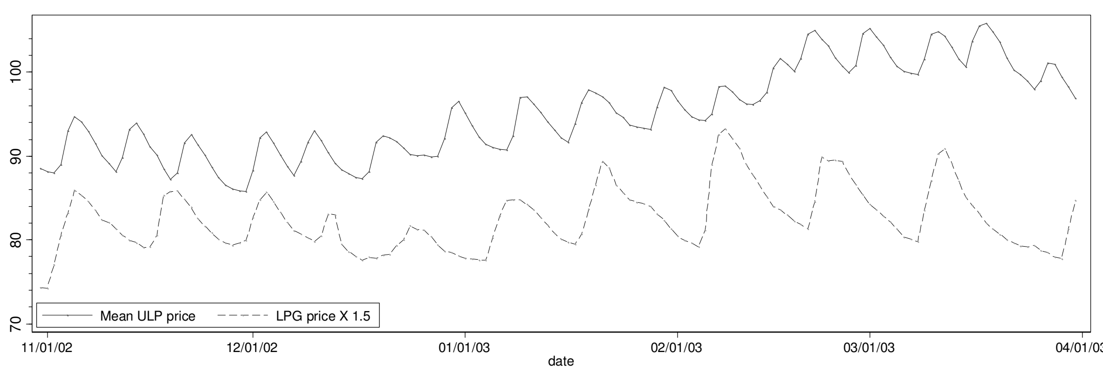


Figure 3: Daily Market Average Gasoline and Scaled LPG Prices in the Perth Market, 11/01/02 - 04/01/03



Note: LPG price is scaled by a factor of 1.5.

2. Background

LPG, a mixture of propane and butane, is a popular alternative transport fuel heavily promoted by a number of countries (e.g., Australia, Turkey, Poland, Italy, and South Korea) primarily due to environmental considerations. However, very little has been written about LPG in the academic literature, so we first offer an overview of the significance and characteristics of LPG as a transport fuel. We then describe the Perth LPG market and the data used in this paper.

2.1. LPG as a Transport Fuel in Australia

For many years, the Australian government has promoted LPG as an alternative transport fuel on the grounds of environmental protection and energy security. LPG is thought to be less harmful to the environment,[4] and Australia is thought to have an abundant indigenous supply.[5] To promote its use as a transport fuel, the Australian government exempted LPG from the fuel excise tax that was imposed on gasoline and diesel and provides subsidies for consumers who purchase LPG vehicles or retrofit their existing gasoline or diesel vehicles to use LPG.[6]

After gasoline and diesel, LPG is the third most popular vehicle fuel in Australia. Australia has a well-developed LPG distribution system with slightly more than half of the retail gasoline stations also selling LPG (Australian Department of the Environment, Water, Heritage and the Arts 2010, p.7). Australia's Motor Vehicle Census reported a total of 329,592 LPG or LPG-gasoline dual-fuel motor vehicles (2.5% of all motor vehicles) in 2003 and a total of 513,562 LPG vehicles (3.1% of all motor vehicles) in 2011. These LPG vehicles consume about 7% of total fuel by energy content because LPG is heavily utilized by taxis and other high-mileage fleet

[4] In a report to the Australian Greenhouse Office, Beer et al. (2004) find that the life-cycle emissions of LPG vehicles are below those of the equivalent class of gasoline vehicles for all emissions except carbon monoxide.
[5] See Australian Senate Standing Committee on Rural and Regional Affairs and Transport (2007, p.104) for a discussion of Australia's LPG reserves.
[6] See Australian Senate Standing Committee on Rural and Regional Affairs and Transport (2007, p.103) for a discussion of Australian government's LPG vehicle subsidy program.

vehicles (Australian Transport Council and Environment Protection and Heritage Council 2008, p.14).

Most LPG-powered vehicles in Australia are conversions of gasoline engine models (Australian Transport Council and Environment Protection and Heritage Council 2008, p.30). For example, only 12,900 new LPG-capable vehicles were sold in 2007, while 92,000 LPG conversions were undertaken in the same period (Australian Department of the Environment, Water, Heritage and the Arts 2010, p.8). It is important to note that most LPG vehicles in Australia are gasoline-LPG dual-fuel.[7] This means that when an LPG system was added to a car, the gasoline fuel system was retained. A major advantage of dual-fuel vehicles is that they offer drivers the option of switching between gasoline and LPG, thus extending the effective driving range of the vehicle. The downside of dual-fuel vehicles is that they are not optimized for LPG use. Industry publications often recommend that drivers of dual-fuel vehicles use gasoline "from time to time to keep everything [in the gasoline fuel system] working properly."[8]

LPG has a lower energy density than gasoline, so vehicles must use a higher volume of LPG than gasoline to cover the same distance. For example, in 2006, a Ford BF Falcon XT sedan with an automatic transmission and a gasoline engine was rated by the Australian government at 10.9 liters per 100 km, and the same vehicle fitted with an LPG-dedicated system was rated at 15.9 liters per 100 km (Morley 2006), implying a fuel consumption ratio of LPG to gasoline of 1.46. LPG-gasoline dual-fuel vehicles are not optimized for LPG use as LPG-dedicated vehicles are, so the fuel consumption ratio for dual-fuel vehicles may be considerably higher than 1.46.

[7] See statements by Royal Automobile Club of Australia (RACV) at http://www.racv.com.au/wps/wcm/connect/racv/Internet/Primary/my+car/advice+_+information/fuel/liquefied+petroleum+gas+(LPG)+member+information+sheet?CACHE=NONE
[8] "The Pros and Cons of Converting to LPG," http://www.tradingpost.com.au/Research/Cars/The-Pros-and-Cons-of-Converting-to-LPG

2.2. Market Setting and Dataset

Our study is based primarily on a dataset that covers the daily LPG and gasoline prices at every fuel station in the Perth metropolitan area for the period January 3, 2001 to October 31, 2003. The price data was downloaded from a website (www.fuelwatch.wa.gov.au) that was established by the Western Australian government through a law commonly referred to as the 24-hour-rule. This law requires every fuel station in Western Australia to: (1) report to the government its fuel prices for the next day by 2:00 pm today and (2) post the reported prices on its price board at the beginning of the next day and maintain the prices for 24 hours. As a result, fuel firms decide their prices simultaneously (i.e., without knowing rivals' prices) and once every 24 hours.

Of the 377 fuel stations in our dataset, a total of 234 sell LPG:[9] 229 stations sell both gasoline and LPG, and 5 stations sell LPG only. However, the sales volume of LPG is only about 7% of the volume of gasoline.[10] Most of the fuel stations that sell LPG carry the brands of BP (63), Ampol/Caltex (63), Shell (30), Mobil (17), Gull (17), and Peak (17). The first four brands belong to major oil companies, and the latter two are large independent brands in Western Australia. The remaining fuel stations that sell LPG belong to Kleenheat (7), Woolworths Plus (7), and other small brands (13). Woolworths Plus is the fuel brand of Woolworths, a supermarket chain that also sells fuels. Most of the 372 fuel stations that sell gasoline also carry the brands of BP (67), Ampol/Caltex (88), Shell (46), Mobil (23), Gull (38), and Peak (18).

LPG sold at fuel stations in Western Australia is produced by three firms: BP Australia, Wesfarmers, and BHP Petroleum. These three firms' total capacity to produce LPG far exceeds

[9] When analyzing cycling behavior, we do not consider those retail stations whose prices never cycled. There are about 10 such stations, typically in isolated areas.

[10] According to Western Australian Select Committee on Pricing of Petroleum Products (2000, p.1 and p. 17), 1.85 billion liters of gasoline was sold in Western Australia in the 1999/2000 financial year, and approximately 132 million liters of LPG were sold as a transport fuel in Western Australia in 1999.

local demand. It is useful to note that the wholesale arrangements in the LPG and gasoline markets were such that each brand can control the retail prices of most of the stations that carry the brand.[11] We have access to the confidential daily wholesale LPG prices paid by a multi-site BP franchisee for the period of January 1, 2001 to October 31, 2003. These wholesale prices are reasonable proxies for the marginal costs of supplying retail LPG.

3. Theory and Literature

The theoretical foundation of the gasoline price cycle literature is the Edgeworth price cycle equilibrium in Maskin and Tirole's (1988) dynamic oligopoly model. In this model, two identical firms compete over the price of a homogenous product for an infinite number of periods in a market with fixed demand and production cost where firms set price alternatingly. An Edgeworth price cycle has three phases. Let the initiation of a price restoration be the start of a new price cycle. In the falling phase, the two firms undercut each other gradually until price reaches marginal cost. At this point, the firms are in the third phase called the war of attrition phase: both firms wish prices to be increased, but neither wants to raise its price first. Once a firm relents by hiking its price first, the other firm follows with a slightly smaller price hike, and the consecutive price hikes constitute the restoration phase.

When studying the extent to which the observed price cycles can be captured by the Edgworth price cycle theory, the existing gasoline price cycle literature has focused primarily on two sets of features of Edgworth price cycles.[12] The first set of features characterizes cycle structure. A basic and obvious feature of the Edgeworth price cycle is that (1a) the length of the

[11] See Western Australian Select Committee on Pricing of Petroleum Products (2000, p. 17) for details of the wholesale arrangements in the LPG market and Wang (2009) for details of the gasoline market.

[12] The gasoline price cycle literature also examines two other questions that we do not address in this paper: in what types of gasoline markets are price cycles more likely to arise (e.g., Eckert 2003, Noel 2007a, Doyle et al. 2010) and what are the welfare implications of gasoline price cycles (e.g., Lewis and Noel 2011, Noel 2011b, Zimmerman et al. 2011).

restoration phase is shorter than that of the non-restoration phase.[13] Another basic feature of Edgeworth cycle is that (1b) changes in cost or demand cannot explain its existence since both remain fixed in the basic model. Changes in cost, however, are expected to have subtle impacts on cycle characteristics. In the price cycle equilibrium, a restoration does not start until price approaches marginal cost. If marginal cost itself has decreased since the initial restoration, it would naturally take a longer time for price to fall close to marginal cost again. This logic implies that (1c) the length of a cycle tends to be longer if marginal cost is lower at the end of the cycle than at the start of the cycle.

The second set of features characterizes firm behavior, emphasizing that the Edgeworth price cycle is a theory of oligopoly price competition. For this oligopoly theory to be applicable, the price setters in a retail gasoline or LPG market should be a few firms instead of the large number of individual stations. Moreover, the war of attrition problem embedded in the price cycle equilibrium generates the need for oligopoly firms to coordinate price increases (Noel 2008, Wang 2008). The basic intuition is that firms have strong incentive to be the last to increase price; those that increase their prices early lose market share. The gasoline price cycle literature finds that price hikes in cycling markets exhibit high degrees of intrabrand synchronization and uniformity (e.g., Wang 2009 and Lewis 2012), suggesting a small number of brands are price setters. This literature also finds that firms use the facilitating practice of price leadership and followership to coordinate price increases; large brands tend to be leaders, small brands tend to be followers, and followers tend to undercut leaders (e.g., Eckert and West 2004, Noel 2007b, Atkinson 2009, Lewis 2012, Byrne and Ware 2011). The coordination problem at the cycle bottom makes larger firms, which control a large number of retail stations, more natural and

[13] The term non-restoration phase refers to the sum of the falling phase and the war of attrition phase. Since the start of a war of attrition phase is hard to identify in practice, much of the gasoline price literature addresses the falling phase and the war of attrition phase together.

effective price leaders.[14] We examine (2a) whether LPG price hikes exhibit high degrees of intrabrand synchronization and uniformity and (2b) whether firms use price leadership to coordinate price hikes and, if so, how.

Noel (2008) uses computational methods to extend the Maskin and Tirole (1988) model along several dimensions. In particular, Noel finds that aggregate demand elasticity impacts the shape of the price cycle. When aggregate demand is more elastic, firms are less aggressive in undercutting. By undercutting its competitors, a firm can increase its sales volume through two channels: stealing existing consumers from its competitors or attracting new consumers to the market. Firms are less aggressive in undercutting in a market with a more elastic demand curve because a small price cut in such a market can lead to the same sales increase as a larger price cut in a market with a less elastic demand curve. Less aggressive undercutting implies that the non-restoration phase is longer, and given that the length of the restoration phase is fixed in a model with two players, cycles are more asymmetric. Since the aggregate demand for LPG is much more elastic than that for gasoline, Noel's model would predict that LPG price cycles are longer and more asymmetric than gasoline price cycles.

We close this section by noting a discrepancy between theory and reality. Firms in the Maskin and Tirole model, by assumption, always set their prices sequentially, while firms in the Perth LPG market have to set their prices simultaneously due to the 24-hour rule. While fully addressing this discrepancy is beyond the scope of this study, Figure 2 indicates that firms in the Perth LPG market do *increase* their prices sequentially ex post.

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[14] The two firms in the Maskin and Tirole model alternate as the price leader since they relent with equal probability. Eckert (2003) considers two firms of different size and find that for some parameters, the larger firm is more likely to be the price leader. Noel (2007b) and Wang (2008) make the informal argument that the coordination problem at the cycle bottom makes larger firms more natural and effective price leaders.

4. Empirical Analysis

Figure 4 shows the market average LPG retail prices for our entire sample period. LPG price cycles started to emerge in the Perth market in June 2001 but were not regular until January 2002. Since our focus is on equilibrium behavior, we focus on the period of January 2002 through October 2003. We organize our empirical analyses of LPG price cycles into four subsections: basic LPG cycle characteristics, impact of cost changes, intrabrand pricing behavior, and price leadership and followership. Subsection 5 compares LPG price cycles with gasoline price cycles.

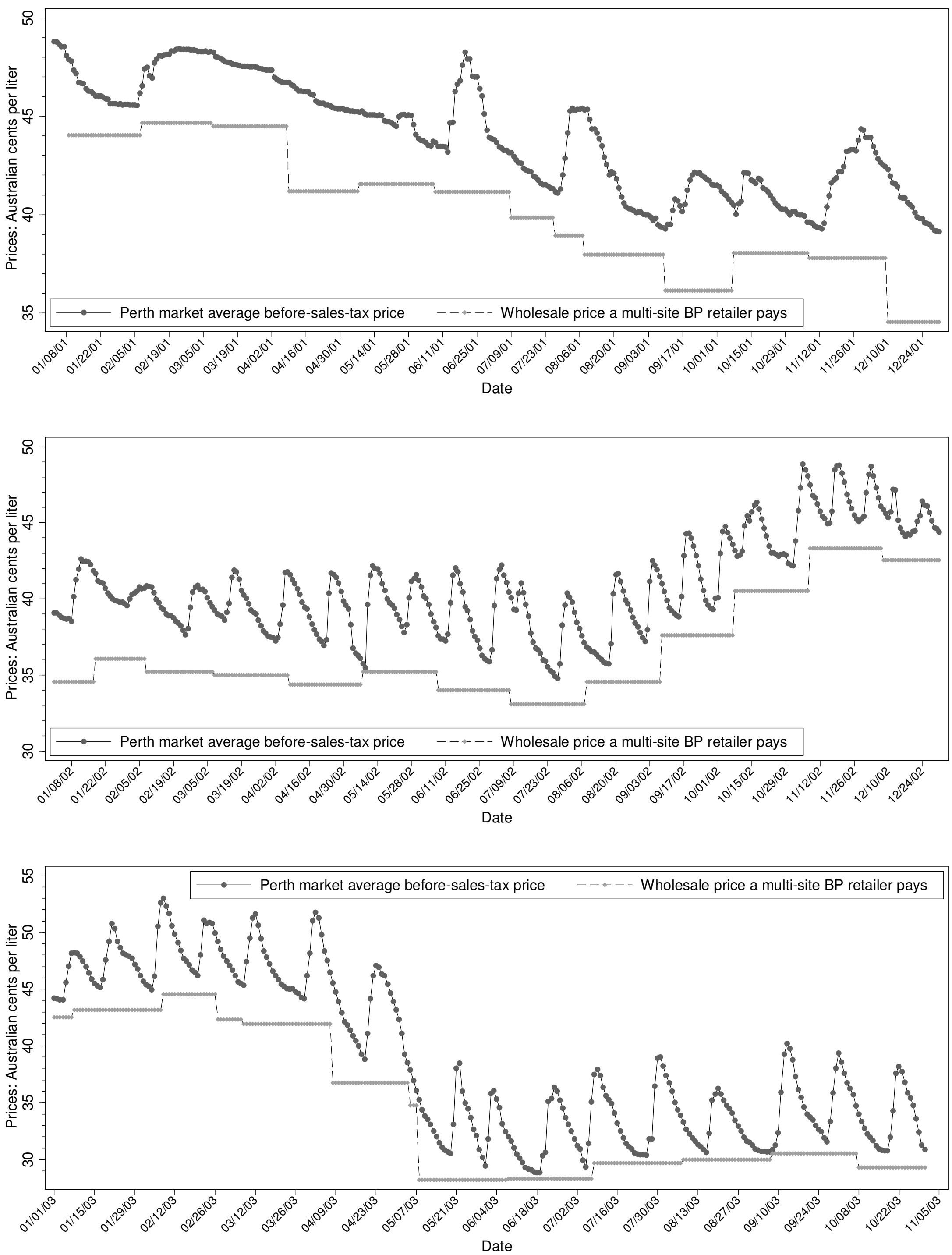
4.1. Basic LPG Cycle Characteristics

As in the Edgeworth cycle theory, we define the lead price hike of a cycle as the first price hike by any brand after a series of small price decreases.[15] The day on which a lead price hike takes place is the start of a new price cycle. The firms that initiate lead price hikes are called price leaders. The length of a price cycle is then the number of days from the start through the end of the cycle. The length of the restoration phase is the number of days from the start day through the peak day. A cycle peak day is a day on which the market average price reaches the maximum level within the cycle period. Figures 2 and 3 indicate that we can identify the cycle start days and the cycle peak days in a clear-cut way.

For the sample period of January 2002 through October 2003, we identify 37 cycles. We do not observe the end of the 37th cycle, so we do not know the length of this cycle. The length of the first 36 cycles ranges from 10 days to 30 days, with the mean and the median both 18 days. The average length of the restoration phase and the non-restoration phase is 4.3 and 13.9 days, respectively. A simple paired *t* test, with a p-value of 0.0000, strongly confirms cycle feature (1a): the length of the restoration phase is smaller than that of the non-restoration phase.

[15] For a brand's price increase to be considered a lead price hike, the brand's average price increase must be at least 1 cent per liter. Almost all lead price hikes are as clear cut as those shown in Figure 2.

Figure 4: Perth Market Average LPG Retail Prices Before Sales Tax



Cycle amplitude can be measured by the height of the restoration phase (i.e., the restoration amplitude) or the height of the falling phase (i.e., the falling amplitude). The average restoration amplitude of the 37 cycles is 5.9 cents per liter, and the average falling amplitude of the first 36 cycles is 6.0 cents per liter. Cycle amplitude is, on average, 14.6% of LPG retail prices, the average of which is 41.1 cents per liter during the sample period with regular cycles. Even though the two average values are close to each other, the values of these two measures are often very different for a given cycle. In fact, the difference between these two measures ranges from -9.1 to 4.2 cents per liter. The two amplitude measures are always equal to each other in the Maskin and Tirole model where marginal cost is fixed, but these two measures may differ for some LPG cycles as the marginal cost of supplying retail LPG changes over time. The next subsection studies the difference between the two amplitude measures further.

Of the 37 cycles, 15 start on Sunday, 3 on Saturday, 4 on Monday, 4 on Tuesday, and 5 on Friday. The fact that nearly half of the cycles start during the weekend leads one to suspect that demand might play a role. A price leader has the incentive to start a price hike on a day with relatively low demand so that its loss of market share is relatively small. However, we cannot offer any evidence for or against this hypothesis as we do not observe daily LPG demand.

4.3. Impact of Cost Changes

Figures 2 and 4 support cycle feature (1b) that changes in cost cannot explain the existence or the dynamics of the LPG price cycles.[16] Retail LPG prices change much more frequently than wholesale LPG prices do. The data also supports cycle feature (1c) that cycle length tends to be longer if marginal cost is lower at the end of a cycle than at the beginning of the cycle. Figure 5 shows the impact of cost changes on cycle length. Cost change is defined as the wholesale price paid by the multi-site BP franchisee at the end of a cycle minus the wholesale price paid at the

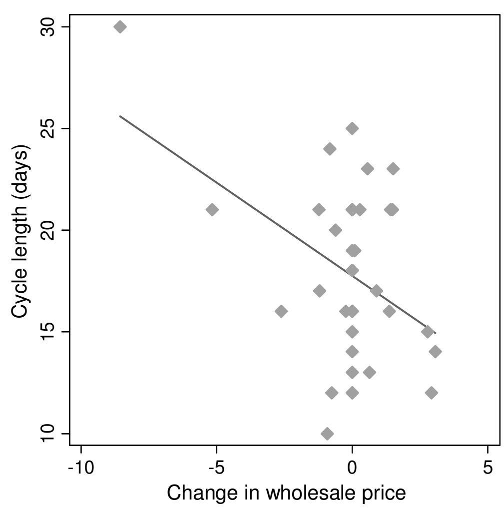
[16] Demand changes cannot explain the existence of LPG price cycles either. Firms face the same market demand every day, yet some firms hike price on certain days while others do not.

beginning of the cycle. If we regress cycle length on cost change and a constant, the coefficient on cost change is – 0.92, with a standard error of 0.33.

Recall that the logic behind Figure 5 is that a price cycle does not end until price falls close to marginal cost, and that if marginal cost has fallen since the start of the price cycle, it takes longer for retail price to fall close to marginal cost again. The same logic also implies that if marginal cost has become lower than it was at the start of a cycle, price should experience a larger fall before it approaches marginal cost again, implying that the amplitude of the falling phase is larger than the amplitude of the restoration phase.

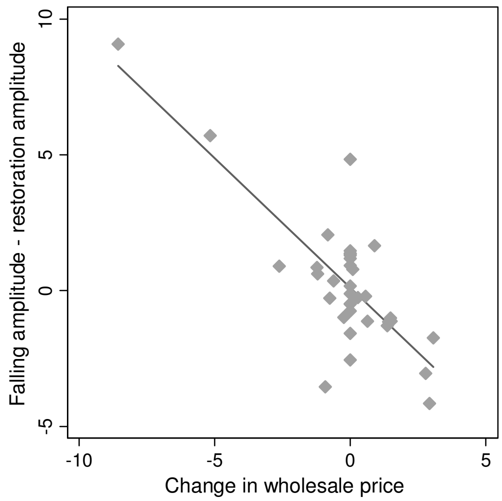
Figure 6 confirms this testable implication. If wholesale price is lower at the end of a cycle than at the beginning, the height of its falling phase tends to be larger than the height of its restoration phase. In a linear regression in which the dependent variable is the height of the falling phase minus the height of the restoration phase and the explanatory variables are cost change and a constant, the cost change coefficient is – 0.95, with a standard error of 0.13.

Figure 5: Impact of Cost Changes on Cycle Length



Note: The x axis is the wholesale price paid by the multi-site BP franchisee at the end of a cycle minus the wholesale price paid at the beginning of the cycle.

Figure 6: Impact of Cost Changes on Cycle Amplitude



Note: The x axis is the wholesale price paid by the BP multi-site franchisee at the end of a cycle minus the wholesale price paid at the beginning of the cycle. Falling amplitude is the height of the falling phase, and the restoration amplitude is the height of the restoration phase.

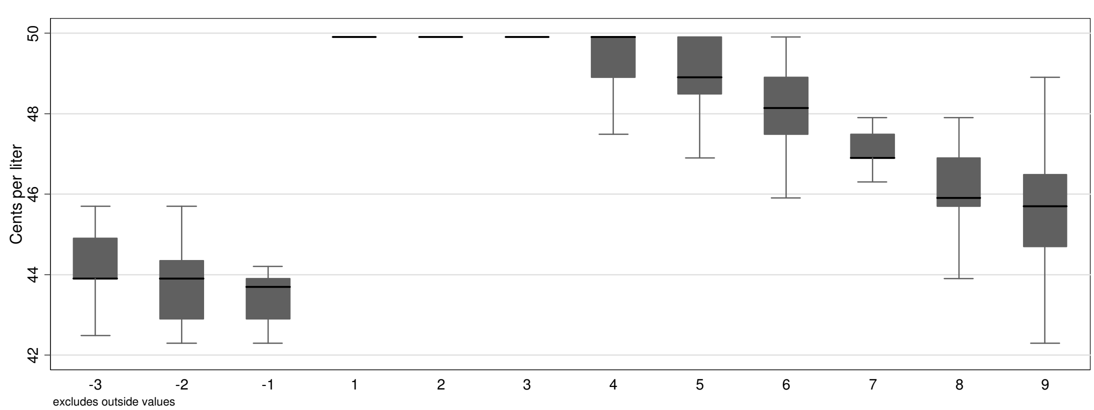
4.3. Intrabrand Pricing Behaviors

A conspicuous feature in Figure 2 is that firms hike their prices sequentially. For this sequential pattern of price hikes to emerge, there must be some degree of intrabrand synchronization in price hikes. In this subsection, we present further evidence that LPG price hikes, but not price decreases, exhibit a high degree of intrabrand synchronization and uniformity. Before doing so, it is useful to recall why this pattern is consistent with the Edgeworth price cycle equilibrium. Intrabrand synchronization and uniformity dramatically reduces the number of price setters from over 200 fuel stations to a few oligopoly firms and allows firms to send unambiguous signals to competitors, thus facilitating pricing coordination. Why is intrabrand synchronization and uniformity present in price hikes but not in price decreases? At the bottom of each cycle, a war of attrition problem exists that requires coordination, while no such problem exists during the falling phase.

Figure 7(a) shows, by cycle day, the box-whisker plots of BP-branded stations' LPG prices before and during the 15th cycle in our sample. This cycle was led by BP alone. The x-axis indicates cycle days: 1 is the first day of the 15th cycle, and -1 is the day immediately before the start of the 15th cycle or the last day of the 14th cycle. This figure shows that most of the BP-branded stations' LPG prices were hiked to a single price (49.9 cents per liter) in the first three days of the 15th cycle, but these stations' prices exhibit considerable levels of price dispersion before and after the restoration phase of this cycle.

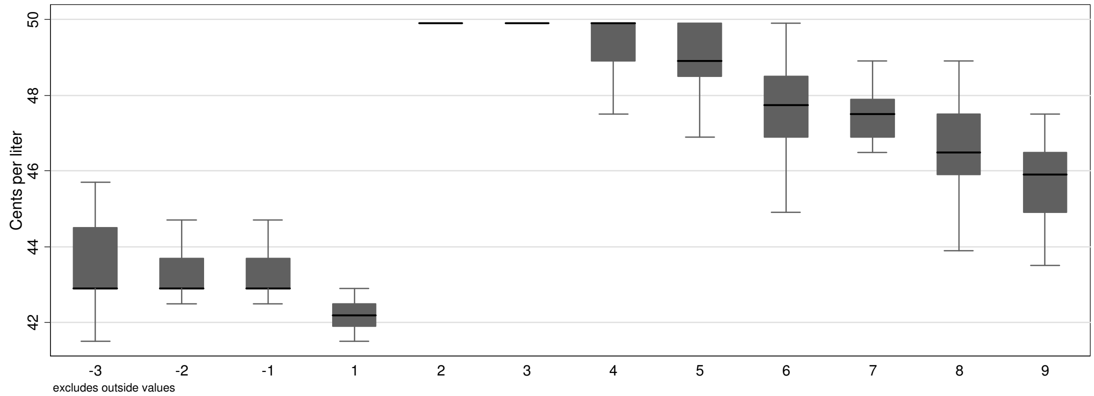
Figure 7(b) shows, by cycle day, the box-whisker plots of Shell-branded stations' LPG prices before and during the 15th cycle. Shell's prices exhibit some dispersion on the first day of the cycle as Shell was not a leader for this cycle. On the second day of the cycle, Shell followed BP's lead price hike by hiking most of its prices to exactly 49.9 cents per liter. This is why Shell's prices collapsed to a single point in figure 7(b) on the second day of the cycle. It is useful to point out that BP, Caltex, Shell, and Mobil, if not a leader of a cycle, almost always hiked the majority of their retail LPG prices to exactly the same level as the one to which the price leader hiked (most of) its prices.

Figure 7(a): Box Plots of BP Stations' Prices before and during a Price Cycle Led by BP



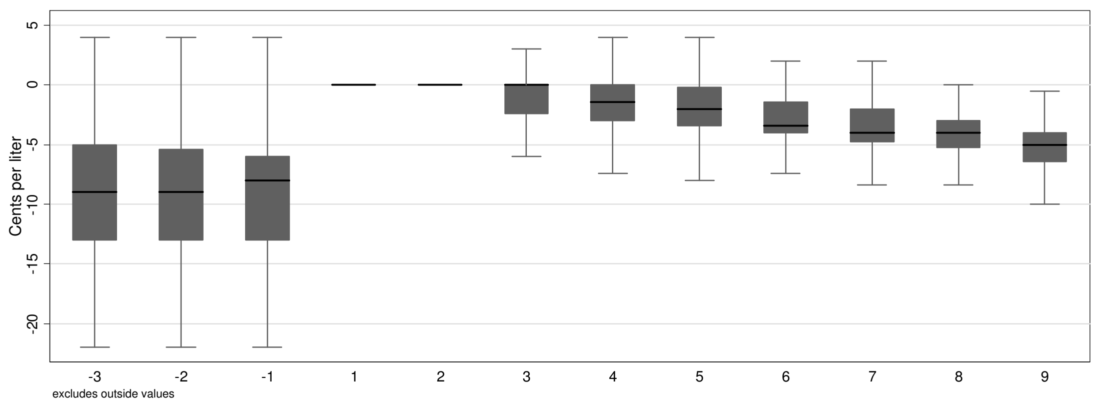
Note: The x-axis is cycle days: 1 is the first day of a cycle, and -1 is the day immediately before the start of the cycle.

Figure 7(b): Box Plots of Shell Stations' Prices before and during a Price Cycle Led by BP



Note: The x-axis is cycle days: 1 is the first day of a cycle, and -1 is the day immediately before the start of the cycle.

Figure 7(c): Box Plots of BP Stations' Prices across 11 Cycles Led by BP Alone



Note: The x-axis is cycle days: 1 is the first day of a cycle, and -1 is the day immediately before the start of the cycle.

The patterns observed in Figures 7(a) and 7(b) hold across other cycles. To illustrate, we follow Lewis' (2011) method of plotting normalized prices. Define the restoration price of a cycle as the mode price charged by the leader brand. For example, the restoration price of the 15^{th} cycle is 49.9 cents per liter, the mode price charged by BP stations. We then obtain the normalized price of a station on any day of a cycle by subtracting the restoration price of the cycle from this station's price on that day. Normalized prices on any day measure the difference from the restoration price of the corresponding cycle, making them comparable across cycles. Figure 7(c) shows, by cycle day, the box plots of BP stations' LPG prices across the 11 cycles for which BP was the sole leader. Again, the distribution of BP stations' prices collapsed on the first two days of the 11 cycles that it led alone. In fact, of the 583 normalized BP prices on the first days of the 11 cycles, 455 prices are 0, 123 prices are smaller than 0, and only 6 are bigger than 0. Almost all of the 123 normalized prices that are smaller than 0 are those of the stations that had not yet hiked prices on the first day of a cycle. BP's prices are dispersed on the third day in this figure because BP started to cut some stations' prices on the third day of some cycles.

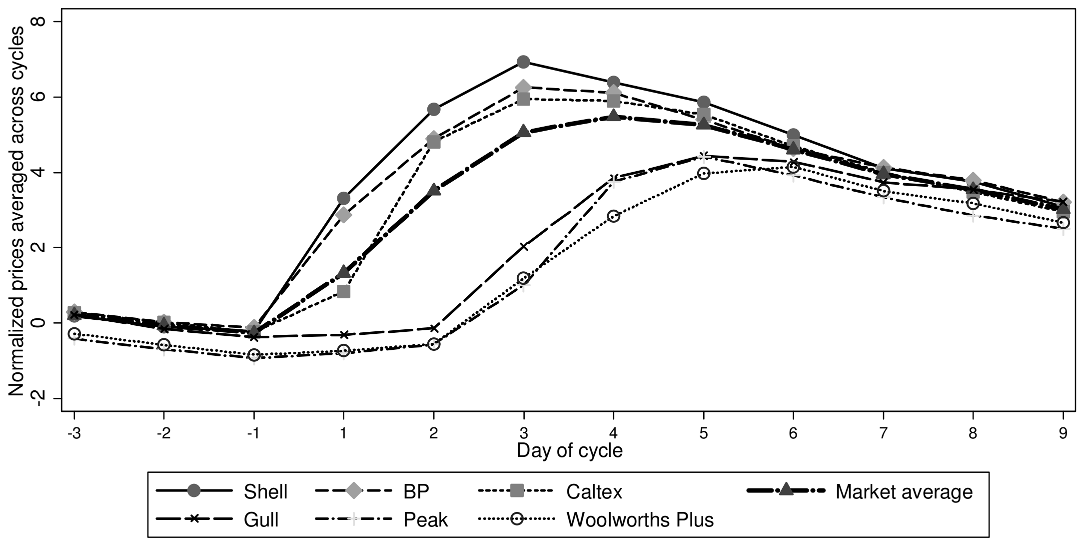
4.4. Price Leadership and Followership

Figure 2 indicates firms hike their prices sequentially, generating a conspicuous pattern of price leadership and followership. In this subsection, we summarize the price leadership and followership patterns across the 37 regular LPG price cycles in our sample.

Of the 37 cycles, 18 are led by Shell alone, 11 by BP alone, 3 by Caltex alone, and 1 by Mobil alone. Four cycles are co-led, with multiple brands initiating price hikes on the same day. Two of these cycles are co-led by Shell and BP, 1 by Caltex and BP, and 1 by Caltex and Shell. In sum, BP was a price leader for 14 cycles, Caltex for 5 cycles, and Shell for 20 cycles. Price leaders in this LPG market are essentially the three largest LPG firms. Co-leadership is a by-product of the 24-hour-rule, under which firms must decide whether to hike price without knowing rivals' prices. This uncertainty about rivals' actions may lead firms to hike price on the same day.

One way to summarize firms' leader-follower behavior is to consider a representative cycle. We use normalized prices to construct a representative or average cycle. We subtract the market average price on the day immediately before the start of the current cycle from each station's LPG price on each day of a cycle. Figure 8 shows, by brand and cycle day, the normalized prices averaged across the 37 cycles. Market average price reaches its highest level on the fourth day of the representative cycle. The six brands in this figure sort themselves into two groups: Shell, BP, and Caltex, the price leaders, generally have above market average prices; and Gull, Peak, and Woolworths Plus, the price followers, have below market average prices. During the restoration phase, the three follower brands' prices are much lower than those of the leader brands, and during the falling phase, the price differences among the brands are fairly small.

Figure 8: Normalized LPG Prices Averaged across the 37 Cycles



Note: The x-axis is cycle days: 1 is the first day of a cycle, and -1 is the day immediately before the start of the cycle.

To show the precise price differences among the brands on various cycle days, we report in Table 1 the results of a regression in which the dependent variable is a station's daily price and the independent variables are brand dummies. (The results are very similar if we use normalized prices as the dependent variable in this regression.) The constant term represents the price level of Peak-branded stations, and the slope coefficients are differences from Peak stations' prices. The prices of the major oil firms are always higher than those of Peak or Woolworths Plus, and the difference is larger during the restoration phase than during the falling phase. On cycle day 3, the prices of Shell, BP, Caltex, and Mobil are all over 5 cents per liter higher than those of Peak or Woolworths. The major oil firms' prices are also higher than Gull's during the restoration phase, but not during some of the falling days. Woolworths Plus tends to have the lowest retail LPG prices. On cycle day 1, Shell and BP have the highest prices as they are the most frequent price leaders.

Table 1: Estimated Price Differences among Brands on Various Cycle Days

	Cycle Days						
	-1	1	3	4	5	8	9
Shell	0.89***	4.45***	6.38***	3.06***	1.84***	1.20***	0.85***
	(0.12)	(0.64)	(0.56)	(0.45)	(0.22)	(0.15)	(0.17)
BP	0.79***	3.99***	5.90***	2.97***	1.49***	1.23***	0.94***
	(0.16)	(0.71)	(0.38)	(0.44)	(0.17)	(0.16)	(0.14)
Caltex	0.78***	1.79***	5.31***	2.50***	1.46***	0.87***	0.68***
	(0.13)	(0.47)	(0.59)	(0.42)	(0.20)	(0.14)	(0.12)
Mobil	1.47***	1.59***	5.36***	3.18***	1.93***	1.32***	1.14***
	(0.22)	(0.25)	(0.56)	(0.38)	(0.22)	(0.15)	(0.19)
Gull	0.86***	0.83***	1.37***	0.44	0.36	1.01***	1.05***
	(0.17)	(0.17)	(0.49)	(0.34)	(0.22)	(0.18)	(0.20)
Woolworth	-0.43	-0.37	-0.25	-1.34**	-0.88*	-0.14	-0.16
	(0.30)	(0.31)	(0.48)	(0.58)	(0.44)	(0.35)	(0.36)
Minor brands	0.67***	0.81***	0.99**	-0.13	-0.00	0.49***	0.46***
	(0.10)	(0.12)	(0.39)	(0.31)	(0.18)	(0.11)	(0.12)
Constant	40.78***	40.89***	42.69***	45.44***	46.11***	44.38***	44.07***
	(1.05)	(1.02)	(1.12)	(0.94)	(0.88)	(0.99)	(1.01)
# of cycles	37	37	37	37	37	32	30
# of obs.	7,284	7,265	7,268	7,266	7,268	6,264	5,848
R-squared	0.0029	0.0502	0.118	0.0453	0.0154	0.0048	0.0033

Note: Day -1 is the last day of the previous cycle or the day immediately before the first day of the current cycle.
The constant represents Peak's retail LPG prices. In parentheses are robust standard errors (clustered by cycle).
*** Significant at the 1% level; ** significant at the 5% level; * significant at the 10% level.

The normalized prices of the three leader firms in Figure 8 increase on each of the first three cycle days. This does not mean that brands increase the price of individual stations three times during the restoration phase. Individual stations essentially always hike price in a single jump. The normalized prices averaged across cycles increase on consecutive days for two reasons. First, a brand's behavior may differ across cycles. A large brand may be a leader in some cycles, but a second- or third-day follower in other cycles. Once averaged across cycles, price will increase on consecutive days. Second, intrabrand synchronization is not perfect. A small proportion of a brand's stations may not hike price on the same day as the brand's other stations.

4.5. Comparison with Gasoline Price Cycles

The LPG price cycle dynamics documented in previous subsections are similar to those of gasoline price cycles studied in the existing literature (e.g., Wang 2009). However, there is a major difference between LPG cycles and gasoline cycles in the Perth area: LPG price cycles are much longer and more asymmetric than gasoline price cycles.

From January 2002 to October 2003, there were a total of 76 full gasoline price cycles, which is more than twice the number of LPG price cycles during the same period. Hence, the average length of the gasoline price cycles, which is 8.6 days, is less than half the average length of the LPG price cycles, which is 18 days. (The length of the gasoline price cycles range from 5 days to 14 days, with a median of 8 days.) For the gasoline price cycles, the average length of the restoration phase and the non-restoration phase is 2.8 and 5.8 days, respectively. Hence, gasoline price cycles are less asymmetric than LPG price cycles; the ratio of the length of the non-restoration phase to the length of the restoration phase is 2.2 for gasoline price cycles and 3.4 for LPG price cycles. Given that gasoline price cycles differ from LPG price cycles in terms of length and degree of asymmetry, it is not surprising that these two cycles, as those in Figure 3, appear to be independent from each other.

Why are the LPG price cycles much longer and more asymmetric? These findings are consistent with Noel's (2008) prediction that price cycles in a market with greater aggregate demand elasticity are longer and more asymmetric. The suppliers and the market structure of the LPG and gasoline markets are essentially the same. The main difference between these two markets lies in the demand side; the demand for LPG is much more elastic than the demand for gasoline because most LPG vehicles can also use gasoline. Noel (2008) also finds that cycles become longer and more asymmetric when firms face tighter capacity constraints. However, we are not aware of any evidence that suggests capacity constraints, if they exist at all, are tighter in the LPG market than in the gasoline market.

5. Conclusion

This paper contributes to the literature on gasoline price cycles by documenting the LPG price cycles in the Perth area of Western Australia and comparing the LPG price cycles with the gasoline price cycles in the same area. We find that the LPG price cycles, similar to the gasoline price cycles, are well characterized by the Edgeworth price cycle model. In particular, we have emphasized the role of intrabrand synchronization and price leadership in generating the regular LPG price cycles. We also find that LPG price cycles are much longer and more asymmetric than gasoline price cycles, which is consistent with the fact that the aggregate demand for LPG is more elastic and that Edgeworth cycles are predicted to be longer and more asymmetric when demand is more elastic. Our paper is the first to compare regular price cycles in two products, and our findings provide empirical evidence on how demand elasticity affects Edgworth price cycles.

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