Gasoline price cycles under discrete time pricing*

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Abstract

We characterise petrol pricing dynamics in an unusual policy environment. A timing restriction in the Western Australian market imposes discrete time pricing on petrol retailers, enabling us to observe the exact timing of price changes. We employ a Markov-switching regression model, finding the existence of Edgeworth price cycles of a similar nature to those recently observed in some other retail petrol markets. Cycles are frequent, asymmetric, and of substantial amplitude. Importantly, firms change prices almost every period, limiting the relevance of the leading theory of Edgeworth cycles due to Maskin and Tirole (1988). We also discuss episodes of disruption and evolution of the price cycle.
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1 Introduction

Regular, distinctive price cycles have recently been documented in retail petroleum markets in a number of cities around the world. Cycles are frequent, highly asymmetric, and of substantial amplitude. They have attracted the concern of consumers, regulators, and

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policy makers.[1] It is likely the striking resemblance of observed price cycles to theories of Edgeworth pricing that has most piqued academic interest. There are many potential explanations for the Edgeworth cycle. However, at least since Castanias and Johnson (1993), the price commitment model of Maskin and Tirole (1988) (hereafter MT) model has been invoked to explain petrol price cycles. We study the nature of price cycles in a setting in which important elements of this leading theory of Edgeworth pricing do not match the data.

We focus on the Western Australian retail petrol market following a recent change in regulatory policy. Starting in January 2001, retailers of petrol in Western Australia (WA) were required to notify the regulator of their prices for the next day for posting on a public website. In addition, retailers were required to fix their prices at their nominated level for 24 hours. This setting affords several benefits to the researcher. First, it enables us to study price dynamics in an explicitly discrete time environment, allowing us to observe the precise timing of price changes. This contrasts with the continuous time environment studied by most of the literature. Further, the comprehensive nature of the policy intervention allows us to obtain a history of prices rather than merely a sample. In addition, we have access to an extensive dataset covering an average of 600 stations with over six years of daily observations. Our data encompasses cross-sectional variation, and also dramatic market events.

We deploy a Markov-switching model in the vein of Noel (2007a,b) to describe the pricing dynamics of a sample of 163 stations north of the Swan River in metropolitan Perth for just over 4 years of daily observations. The Markov-switching model of Noel (2007a) permits an objective characterisation of price cycles. We adopt it here for this reason and to allow direct comparison of cycles in Perth with other price cycles examined in the literature. Given the extent of our sample, it is not surprising that, in addition to price cycles, we observe pricing dynamics of a different character. To accommodate this variety, we embed the model of price cycles in a more general regime-switching framework in the manner of Noel (2007b). Given the greater frequency of our data and our access to a history of prices, we can make more precise conclusions regarding the characteristics of the cycle than Noel (2007b).

We make two main contributions to the literature on price cycles. First, we document price cycles in an environment in which the leading theory does not match a prominent feature of the data. The price commitment model of MT provides the foundation for all recent empirical discussion of petrol price cycles. However, as we shall see, firms change prices in almost every period of a price cycle in Perth. This empirical regularity does not match the alternating moves timing specification of MT. This is not a trivial point. Relative to a model of repeated Bertrand competition, the specification of MT incorporates only three changes: firms choose prices sequentially rather than simultaneously, firms choose prices from a discrete price grid, and firms are restricted to Markov strategies. The timing specification plays a critical role.[2] Further, our empirical setting is uniquely qualified to discern firm timing

[1]For example, since 1999 in Australia, retail petrol price movements have been the subject of a Senate inquiry, at least four competition authority reports, an inquiry by the competition authority, substantial legislative changes in the state of Western Australia, and proposed federal legislation, not to mention considerable consumer ire.

[2]In a generalisation of the alternating moves specification, MT argue that asynchronicity emerges endogenously (see Proposition 9). In this context, it is the restriction to Markov strategies that plays the critical role.

choices. Firms are compelled by law to operate in discrete time. The law also permits access to a history of prices, enabling us to observe every choice of market participants without any gaps. Consequently, a novel aspect of our study is the objective characterisation of price cycles in a setting in which the MT model does not provide a complete explanation for the cycle.

Second, owing to the extent of our sample, we are in a position to study temporal changes in the cycle in a given market. Our sample incorporates several dramatic market events, leading to the interruption and reformation of price cycles, and a change in their character. Price cycles were interrupted by the large scale entry of supermarket chains by takeover. The events surrounding Hurricane Katrina led to a second disruption of the cycle. In addition, the length of a typical price cycle approximately doubles during our sample. The detailed nature of our data enables us not only to characterise the price cycle, but also to deconstruct its interruption, reformation, and evolution.

Let us briefly preview some of our results. First, we identify price cycles that are frequent, strikingly asymmetric, and of substantial amplitude. We are not the first to describe the price cycles of Perth, and we view our characterisation of the cycle in this period as complementary to Wang (2009b) and Australian Competition and Consumer Commission (2007). Wang (2009b) focuses attention on leadership patterns, intrabrand synchronicity and cycle length over a sample period of July 2000 to October 2003. Australian Competition and Consumer Commission (2007) presents aggregate annual information about average cycle length and amplitude over a 15 year horizon. By contrast, we present a quantitative characterisation of the cycle over the period January 2001 to February 2007.

Our next result is to establish our earlier claim: for the price cycles we identify, firms change prices in every period, limiting the applicability of the model of MT in our setting. This opens up the possibility that an alternative mechanism for the cycle is at play in Perth. We do not take a position on the most suitable alternative theory of the cycle here, but we do highlight the range of candidate theories in Section 2. We also do not wish to claim here that this finding extends to general environments. However, we believe that some caution should be exercised before invoking MT as the explanation for retail petrol price cycles. Effectively, our sample affords the first opportunity to test the timing prediction of MT and MT does not satisfy this test.

We uncover empirical regularities in the Perth market that nuance our understanding of the cycle. In many retail petrol markets, oil majors take a leadership role in the relenting phase of the cycle (see, for example, Noel (2007a) for Toronto, Atkinson (2009) for Guelph, Ontario, Byrne and Ware (2011) for 110 markets in Ontario, and Lewis (Forthcoming) for 52 markets in the United States). In a continuous time environment, it is difficult to identify leadership with certainty. By collecting bi-hourly data, Atkinson (2009) comes close to this ideal. In the market we study, discrete time is imposed, permitting us to precisely identify leadership in the cycle. Wang (2009b) also considers the discrete time environment of Perth, finding that the leadership role is resolved with mixed strategies. By contrast, with our extended dataset, we find that consistent price leadership by a single firm, BP, emerges follow-

Whether alternating moves are imposed or predicted is not central to our conclusion that MT does not match important elements of the Perth data. For additional discussion see de Roos (2010).

ing disruptions to the cycle. This suggests the role of mixed strategies emphasised by Wang (2009b) is not robust to an extension of the sample. We find that independent and major firms adopt markedly different behaviour in the cycle. Consistent with the cycles observed by Noel (2007a), major firms tend to lead the cycle and participate fully in the cycle. In contrast to Noel (2007a), the cycles associated with independent firms tend to be substantially muted relative to the majors.

We also identify a substantial impact on the cycle due to the wholesale price shock associated with Hurricane Katrina. Lewis (2009) documents the impact of Hurricanes Katrina and Rita on the price cycles of a range of cities in the United States, finding that cycles were disrupted for roughly 40 days. By comparison, price cycles in Perth were disrupted for over three months.

Some of our more interesting results relate to the behaviour and impact of entrants. The entry through takeover of two supermarket chains severely disrupted the price cycle. The entrants were then the principal stumbling block to the reformation of the cycle. It was not until after a further disruption associated with Hurricane Katrina that the supermarket chains became full participants in the price cycle. Once they were integrated into the cycle, the length of the cycle approximately doubled.

The rest of the paper develops as follows. Below, we briefly discuss related empirical literature. In section 2, we provide a brief discussion of the theory of Edgeworth cycles, highlighting the breadth of candidate theories of the cycle and the central role of asynchronous timing to the MT theory of the cycle. In section 3, we describe the industry and regulatory context and introduce the data. In section 4, we outline a Markov-switching model to characterise the price cycle. Section 5 contains our main results. We first characterise the nature of pricing dynamics for the year 2003 using our Markov-switching model. We then use the model to summarise the characteristics of the cycle over time. We also discuss episodes of disruption and evolution of the cycle. Finally, section 6 concludes.

1.1 Related literature

A number of authors have empirically examined the nature of petrol price cycles. Most closely related to our work is that of Noel (2007a,b), who employs a Markov-switching regression framework to describe dynamic pricing patterns. Noel (2007a) uses twice daily data to characterise price cycles for 22 retail petrol stations in Toronto for 131 days in 2001. He finds that cycles are strongly asymmetric and last for an average of about 1 week. Small firms tend to lead the cycle in the undercutting phase, while large firms tend to relent first. Noel (2007b) employs weekly data for 19 Canadian cities over a period of 10 years to describe pricing dynamics. Cycles are found to be more prevalent, have larger amplitude, be more frequent, and less asymmetric in markets with a greater concentration of independent firms. Cycles are also found to be more prevalent when population density and outlet density are higher.

Because of the continuous time environment in which firms set prices in most retail petrol markets, it is difficult to infer the exact timing of price changes. Atkinson (2009) and Atkinson et al. (2009) use high frequency (2 hourly) data to examine the timing of price changes in Guelph, Ontario. The authors find that price increases are highly predictable and coordinated across neighbouring regions. A new cycle is typically signaled by a temporary price increase by a major firm, and price decreases are relatively rapidly transmitted across stations. By contrast, Doyle et al. (2010) are able to make inferences about the existence of price cycles in 115 United States cities using more limited data. By examining median price changes, the authors conclude that price cycles are more likely to be prevalent in cities with an intermediate level of concentration.

The appeal of the WA policy intervention is evidenced by recent empirical work. Wang (2009b) details leadership patterns in price cycles in the Perth retail petrol market both before and after the regulatory changes. We consider the same institutional setting studied by Wang (2009b), but our work differs in important ways. First, our Markov-switching model permits a quantitative characterisation of the cycle, while this is not a focus of Wang (2009b). Second, we consider a longer panel. This not only allows us to quantitatively describe the cycle as it evolves and discuss important interruptions to the cycle, but it provides additional insights into the nature of the cycle. A major focus of Wang (2009b) is on the use of mixed strategies to resolve a war of attrition at the bottom of the price cycle. With our sample, we can show that this observation is not robust. Price leadership by a single firm emerges in the relenting phase of the cycle later in our sample. We also arrive at a different conclusion to Wang (2009b). While Wang argues in support of the MT theory, we believe that our data provide strong support for Edgeworth cycles in general, but reveal important discrepancies between the data and the MT theory of the Edgeworth cycle. We emphasise that the MT model is one of a range of theories of the Edgeworth cycle.

Wang (2009a) exploits a unique dataset of prices and quantities of petrol retailers in Perth to estimate the short run station-specific demand elasticity for petrol, suggesting that demand is very elastic. Our discussion of the turbulence in the petrol price cycle surrounding the entry of the supermarket chains is closely related to Wang (2010). Wang (2010) studies the role of bundling in the retail petrol market, arguing that the supermarket "shopper docket" discount schemes were likely used as an advertising strategy. Wills-Johnson and Bloch (2010) adopt a threshold regression model to examine the determinants of pricing in relenting and undercutting phases of the cycle in Perth. Wills-Johnson and Bloch (2010) focus on the relationship between pricing and market structure, finding that firms on the periphery of a market tend to have higher prices during the undercutting phase.

To our knowledge, the Western Australian policy intervention provides the first opportunity to explicitly test the timing specification of MT, and we are the first to suggest the model is inappropriate in this setting. Based on a study of the Norwegian petrol price cycle, Foros and Steen (2008) interpret the precise regularity of the cycle as suggestive evidence of coordination in the relenting phase of the cycle. Indeed this regularity is also evident in petrol price cycles in Australia,[3] and is suggested by the observations of Atkinson (2009) and Atkinson et al. (2009) in Guelph, Ontario. However, the continuous time setting considered by Foros and Steen (2008) does not permit inferences on the timing predictions of the MT

[3]This is widely known to observers in Australia, is regularly reported in the popular press, and even makes its way into a "Fuel Facts" consumer information pamphlet produced by the Australian Competition and Consumer Commission (see http://www.accc.gov.au/content/index.phtml/itemId/892835).

model. More recently, Clark and Houde (2011) analyse the mechanics of a gasoline price-fixing cartel in Quebec in which firms communicated explicitly to coordinate price increases and decreases. While these collusive markets exhibit asymmetric pricing patterns, pricing dynamics are very different to the regular, frequent asymmetric cycles we observe in Perth. In particular, price rises are much less frequent, and price declines are typically punctuated by extended periods of sticky prices.

2 Edgeworth cycles

A theory of Edgeworth pricing must explain two principal incentives. Firms must have an incentive to *undercut* rivals when rival prices are "high", and they must have an incentive to *relent* and raise price when rival prices are "low". In this section, we make two points related to the theory of Edgeworth cycles. First, we argue that the set of theories providing incentives to undercut and relent is a large one. We briefly discuss three classes of theory that fit the above description. Second, we argue that sequential play is a fundamental element of the MT price cycle equilibrium.

The Edgeworth (1925) model considers simultaneous price competition for a homogeneous product subject to capacity constraints. Two features of the model provide the intuition for price cycles: the discontinuity in demand arising from homogeneous products provides an incentive to undercut, and the capacity constraint of one's rival gives rise to residual demand, providing the incentive to relent when the price of one's rival is low. As de Roos (Forthcoming) notes, these two features are present in a broader class of static models. In addition to capacity constraints, other motivations for Edgeworth cycles include consumer search costs and product differentiation. An empirical limitation of this class of model is that price cycles are not an equilibrium prediction. The models are essentially static, but provide the intuition for a dynamic price path. In order to predict cycles in equilibrium, one must assume that firms play a myopic best response to past prices.

The most popular model of the Edgeworth cycle is provided by MT. MT consider the following environment. Two firms engage in repeated price competition for a homogeneous product, choosing prices from a discrete grid. Firms alternate in price setting, effectively committing them to their price for two periods. The authors look for Markov-perfect equilibria, finding both fixed price and Edgeworth cycle equilibria.[4]

Consider the Edgeworth cycle equilibrium. Because firms choose prices in a homogeneous product environment, the incentive to undercut is strong. Moreover, because of price commitment, undercutting takes on a distinct temporal meaning. Firms can observe their rival's (fixed) price before deciding whether to undercut. The incentive to relent derives directly from this ability to undercut while one's rival's hands are tied. When the market price is low, by undercutting a firm can capture the market at a low or zero profit margin. By relent-

[4]The model of MT is found to be robust to several generalisations. If we allow firm market share asymmetries (Eckert, 2003), differentiated products, i.i.d. cost shocks, capacity constraints, or three firms (Noel, 2008), or a mixture of searching and non-searching consumers (Robertson, 2008), Edgeworth cycles are still observed in equilibrium.

ing, the firm will make no sales in the current period, but because of this ability to undercut, the firm has the prospect of future sales at a high profit margin in the near future. In fact, the theory predicts a war of attrition at the base of the cycle. Both firms would rather their rival raise price first as it affords them the first opportunity to undercut at a high price.

It is worth emphasising that sequential play is fundamental for each phase of the cycle. Under sequential play, a firm can undercut without considering the simultaneous action of their rival. By contrast, under simultaneous play, each firm's myopic reaction function specifies undercutting any rival price above marginal cost, but we will not observe undercutting in equilibrium under most standard equilibrium concepts.[5] It is also sequential play that drives the incentive to relent. That is, future profit opportunities stem from the ability to undercut while the price of one's rival is fixed at a high level.

Edgeworth cycles could also be observed in a standard simultaneous-move repeated games environment. If we relax the restriction to Markov strategies of MT, and permit punishment for off-equilibrium behaviour, a simple application of the folk theorem suggests the existence of equilibria with price cycles if players are sufficiently patient. By itself, this explanation for a price cycle is not completely satisfactory. If a price cycle can be sustained, then we could also identify a sustainable fixed price equilibrium that is more profitable.[6] The challenge for a theory of the price cycle in a repeated games environment is then to explain why a price cycle would be more robust, or more likely to emerge than a fixed price.[7]

3 Data and industry background

Over the period of our sample, the Australian petroleum market was characterised by a high degree of concentration and vertical integration.[8] Four firms (BP, Caltex, Mobil, and Shell; hereafter the *oil majors*) dominated the refining, importing and distribution of petrol; and directly or indirectly controlled a substantial share of retail petrol outlets.[9] Supermarkets

[5] Notice that this is true whether firms play Markov strategies in the sense of MT (and hence cannot punish off-equilibrium behaviour), or if punishment is permitted. If firms can only condition on payoff-relevant information (the Markov assumption), we are left with repeated marginal cost pricing, subject to the fineness of the pricing grid (see footnote 13 of MT for details). If punishment is allowed, as we discuss below, the rationale for a cycle is not obvious.

[6] To see this informally, suppose the existence of a collusive equilibrium with price cycles on the equilibrium path. The most difficult point to sustain on the equilibrium price path is the peak of the cycle. Consider a candidate collusive equilibrium with prices fixed at the peak, and notice that punishment will be more effective under the fixed price path because future profits will be higher under cooperation. Hence, the fixed price path will be both more profitable, and easier to sustain.

[7] While this is indeed a challenge, we view this last class of theories the most promising. All three classes of theory are consistent with the basic characteristics of the cycle, but only a repeated games theory provides a prominent role for coordination, a conspicuous feature of many markets with price cycles.

[8] For a useful recent summary of the structure of the Australian petroleum market, see Australian Competition and Consumer Commission (2007).

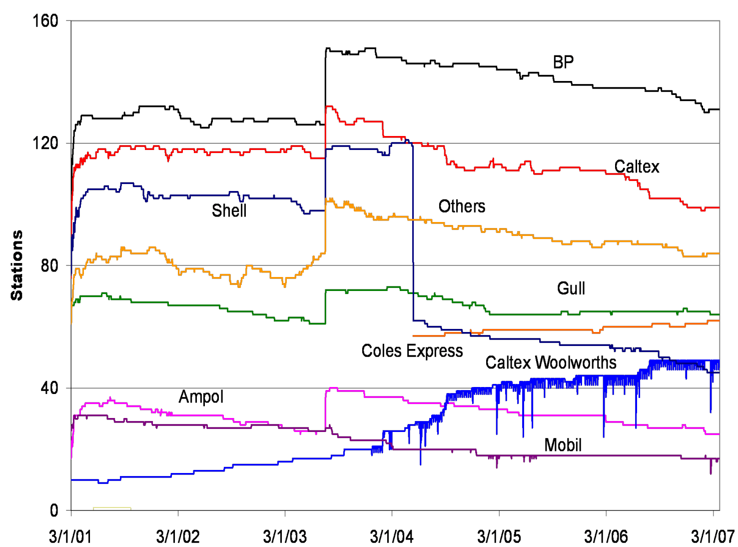
[9] More recently, Mobil has essentially exited the Australian retail petroleum market. Mobil's sites in Western Australia were acquired by United Petroleum in 2007, and in 2010, 7-Eleven Stores acquired the retail fuel business of Mobil, comprising 295 sites.

controlled a substantial minority of retail outlets, with the remainder operated by independent firms.

In the state of Western Australia (WA), BP operated the only refinery. Caltex and Shell obtained wholesale petrol through 6 month contracts with BP, while Mobil imported fuel from Singapore, and independent firms bought primarily on the spot market. While legislation[10] limited the number of sites oil majors could directly control in our sample period, in practice the majors were able to exert considerable influence on stations carrying their brand.[11]

Figure 1, derived directly from our dataset, depicts the evolution of the number of retail sites covered by the Fuelwatch program in WA by brand following the introduction of the program. It illustrates some recent market developments. First, note that the spike in the number of outlets on 21 May 2003 does not reflect a structural change, but rather signifies an expansion in our data set due to the inclusion of additional geographic districts in the scheme. In addition, the downward spikes in the Caltex Woolworths series reflects occasional non-reporting of prices by individual stations, predominantly on Sundays. Second, the market share of supermarket brands increased dramatically over the sample, rising to around 20% by January 2007. This expansion takes place largely at the expense of the oil majors, whose share drops from around 2/3 to 1/2. The entry of Coles Express was through a takeover of Shell outlets, taking effect in WA on March 15, 2004. Woolworths entered by forming a joint venture with Caltex, with the rebranding of sites occurring gradually over the sample period. Finally, a substantial number of sites closed during the sample, primarily in metropolitan areas.

Figure 1: Stations covered by Fuelwatch, by brand



[10]The Petroleum Retail Marketing Sites Act 1980 restricted the number of sites under the direct control of oil majors, while placing no restrictions on non-majors. The Act was repealed in March 2007.

[11]The primary mechanisms were a conditional price support scheme employed by Caltex, and the use of multiple-site franchises by Shell, Mobil, and BP. See Wang (2009b) for further details.

The introduction of shopper docket schemes coincided with the market share push of the supermarket brands. Under these schemes, customers receive a discount (typically 4 cents per litre in our sample) for petrol purchases if they purchase at least $30 of groceries at the associated supermarket. While Woolworths offered some discounts of this nature to customers as early as the mid 1990's, the scheme took off in Australia in 2003 with an alliance between Coles and Shell in May, and between Woolworths and Caltex in August. In November 2003, the Independent Grocers of Australia (IGA) began offering grocery discounts for fuel purchases of any brand.

From our own selfish perspective, the most important recent event is the introduction of the Fuelwatch program (hereafter, *Fuelwatch*), upon which our data is based. Fuelwatch commenced on January 3, 2001. Under the scheme, all petrol retailers must notify Fuelwatch by 2pm of the price they will set tomorrow. This price information becomes publicly available online at 2:30pm, and prices must be fixed at the nominated price for 24 hours commencing 6am the next day. Consumers are thus able to obtain retail price information before they hop into their cars. Because of the way the Fuelwatch program is set up, consumers, competitors, and the researcher have access to the entire history of prices of each of the sites in our dataset.

Fuelwatch was expanded on December 19, 2002 to include wholesale *terminal gate prices*. Wholesale suppliers are compelled to post online and honour spot prices at the terminal gate. Terminal gate prices are determined by the cost of imports from Singapore.[12] There are no cycles in terminal gate prices. Consequently, the retail petrol price cycle reflects a cycle in the retail margin.

Our petrol price data was obtained from the Department of Consumer and Employment Protection (DCEP), who operate Fuelwatch. The dataset contains daily retail petrol prices for an average of about 600 sites for the period January 3, 2001 to January 24, 2007. Approximately 80% of the retail sites in Western Australia are represented. Retail prices are supplemented with Terminal Gate Prices (TGPs), available from December 19, 2002 to January 24, 2007. We match TGPs to retail sites based on brand and proximity. If possible, we use the nearest terminal gate of the same brand. Where the brand operates no terminal gates in WA, we use the nearest terminal gate of any brand.

The data include metropolitan and regional areas. Price cycles are observed only in metropolitan areas, and hence we restrict our sample to these areas. For our empirical model, we consider all stations operating in metropolitan Perth north of the Swan River; a total of 163 stations.[13] We consider various subsamples beginning with the availability of TGPs on December 19, 2002. Even with this restriction, our dataset exhibits substantial variation with which to identify our empirical model. We observe a variety of different kinds of stations, with large and small brands, and integrated and non-integrated brands. In addition, because of the length of our sample, our data encompasses dramatic variation in oil

[12] See Wang (2009b) for additional details.

[13] The selection of this sample is driven by computational considerations. In our empirical model, we estimate rolling Markov-switching regressions. Incorporating the entire set of metropolitan stations is computationally expensive. The Swan river provides a convenient delineation of the market. The character of the cycles does not differ between the north and south side of the Swan river.

Table 1: Summary statistics

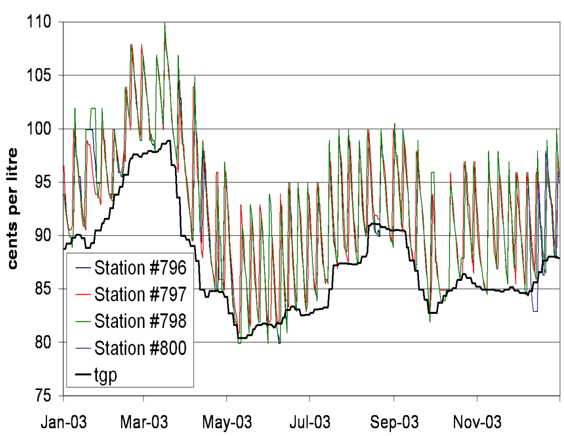
	Mean	Std. dev.	Minimum	Maximum	Observations
	January 1, 2003 - December 31, 2003				
Retail price	92.46	7.195	78.90	125	54,636
Gate price	87.51	4.802	79.57	103.81	54,636
$follow$	0.281	0.450	0	1	54,636
$position$	4.949	5.627	-8.54	44.31	54,636
	December 19, 2002 - December 31, 2006				
Retail price	105.83	15.23	78.90	154	210,946
Gate price	102.55	14.74	79.57	139.92	210,946

prices as well as the market developments described above.

Table 1 contains summary statistics for the 163 stations we use in our empirical model. The top panel describes a subsample of the data for 2003 that we analyse in Section 5.1, and the bottom panel describes the dataset used for our rolling regressions of Section 5.2. The variables $follow$ and $position$ are described in Section 4. Note that the most extreme values for the $position$ variable correspond to stations that do not have a price cycle.

We conclude this section with a snapshot of the data. Several distinct pricing patterns are evident. Figure 2 depicts the unleaded petrol prices of the 4 stations in suburb #249 in our dataset. The left panel shows prices for the year 2003 and the right panel focuses on 3 months in 2003. The solid black line shows a simple weighted average of the terminal gate price for this suburb. The price cycles are striking. They last for approximately 1 week. Price rises are of the order of 10% and occur in a single day; while price falls occur gradually. The identity of the price leader varies over time.

Figure 2: Suburb #249



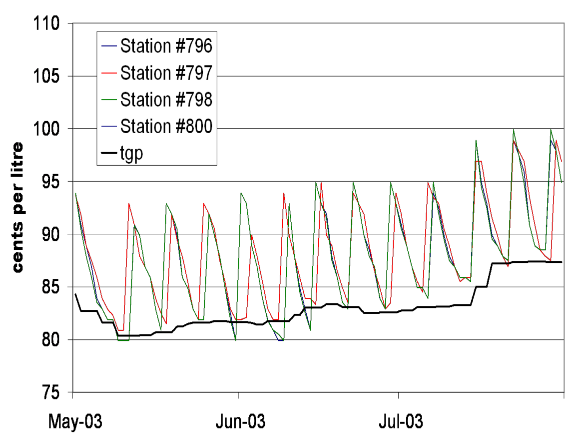


Figure 3 depicts price dynamics of a different nature. The left panel shows prices for the single station in suburb #12. Retail prices appear to display a relatively constant markup over the terminal gate price. A limited degree of price stickiness is apparent. The right panel shows the stations in suburb #64. One station displays regular cycles, while the remaining two stations show a pronounced degree of price stickiness.

Figure 3: Suburbs #12 and #64

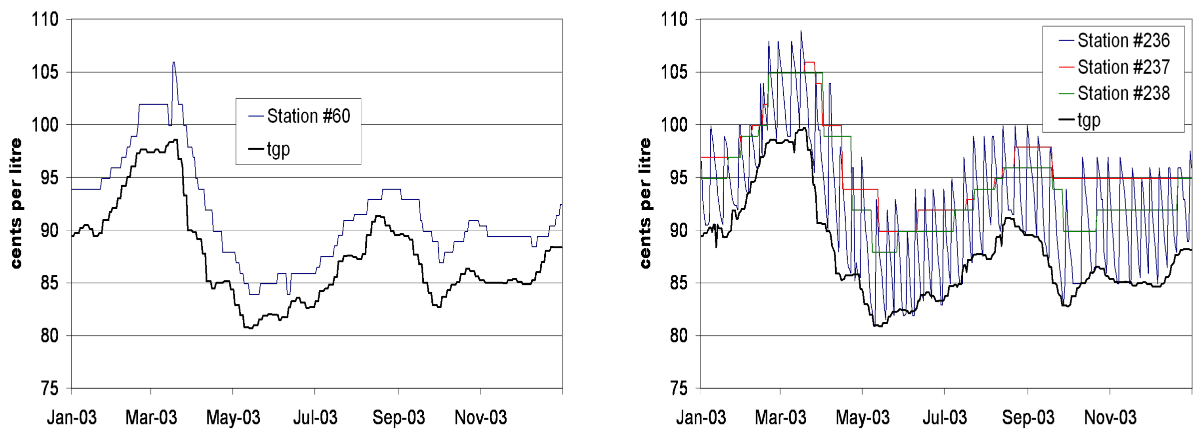
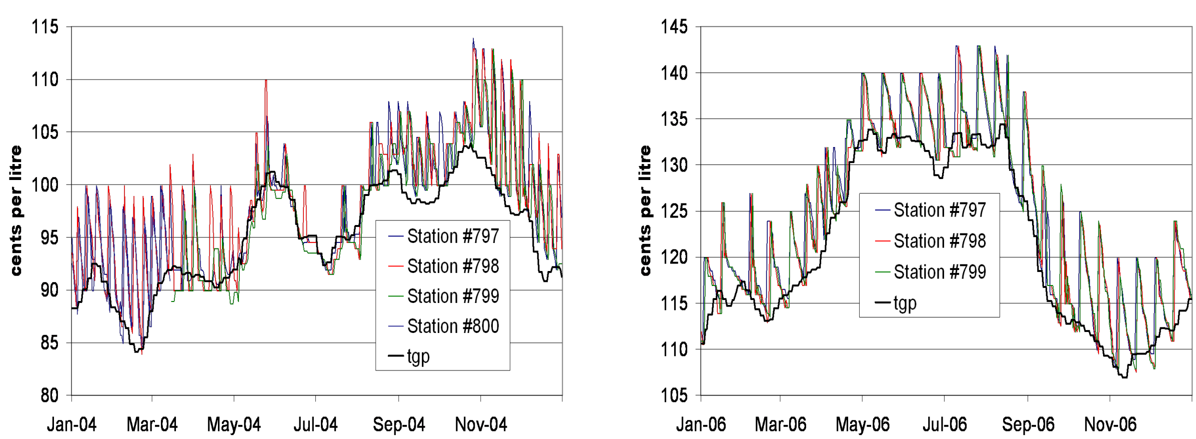


Figure 4 re-examines suburb #249 in years 2004 and 2006. In 2004 (left panel), the price cycles were disrupted for several months. This occurs shortly after the takeover of Shell outlets by Coles Express. It is more than seven months until the original character of the cycles returns. This pattern is observed for many stations in the sample. In 2006 (right panel), we can see a more subtle change. We again have regular price cycles, but they have become noticeably less frequent. We return to discuss these market changes in section 5.2.1.

Figure 4: Suburb #249 after takeover wave



4 Empirical model

To capture the distinct pricing patterns in the data, we follow Noel (2007a,b) in adopting a Markov-switching regression model. The price cycles we observe in metropolitan WA are remarkably similar to those observed in Toronto by Noel (2007a). Accordingly, our motivation for adopting a Markov-switching model is similar. First, it permits us to account for the pronounced serial correlation in the data. Stations exhibiting a cycle tend to maintain the cycle for extended periods, while extended phases without a cycle are also observed. Further, within the cycle, the undercutting and relenting phases are noticeably asymmetric. Second, the Markov-switching framework permits endogenous identification of regimes. Finally, we can obtain an objective description of the characteristics of the observed cycles.

We model price cycles through two separate regimes: the *undercutting* regime captures the gradual reduction of prices in the downward phase of the cycle; and the *relenting* regime corresponds to the rapid rise in prices marking the beginning of a new cycle. To incorporate stations that do not exhibit a cycle, and periods in which the cycle is interrupted in cycling stations, we also include a non-cycling or *focal* regime. To our undercutting, relenting, and focal regimes, we attach the labels U, R, and F, respectively.

Conditional on being in a specific regime, prices are determined as follows:

$$\begin{aligned} \Delta P_{kt} &= X^i_{kt}\beta^i + \epsilon^i_{kt}, \quad i = R, U && (1) \\ P_{kt} &= X^i_{kt}\beta^i + \epsilon^i_{kt}, \quad i = F && (2) \end{aligned}$$

where P_{kt} and ΔP_{kt} refer to the level and change in the price of retail petrol at station k at time t, respectively; the superscript i refers to the current regime; X^i_{kt} contains a vector of control variables for station k at time t; β^i is a parameter vector; and ϵ^i_{kt} captures unobservable station-specific determinants of price movements. We assume the ϵ^i_{kt} are independently normally distributed with regime-specific variance:

$$\epsilon^i_{kt} \sim N(0, (\sigma^i)^2), \quad i = R, U, F \tag{3}$$

Within the undercutting and fixed regimes[14], we allow for the possibility that a station does not change its price by incorporating a sticky price subregime in which

$$P_{kt} = P_{k,t-1}. \tag{4}$$

The probability of observing the sticky price sub-regime is given by the logit form

$$\frac{\exp(W^i_{kt}\delta^i)}{1 + \exp(W^i_{kt}\delta^i)}, \quad i = U, F \tag{5}$$

where W^i_{kt} contains a vector of control variables for station k at time t, and δ^i is a parameter vector.

[14]Because it is difficult to separately identify sticky prices in the undercutting and relenting regimes, we do not allow for sticky prices within the relenting regime.

The evolution of prices is closed by specifying the process of regime transition. The probability of switching from regime i to regime j is given by the logit form

$$\frac{\exp(W^i_{kt}\theta^{ij})}{1+\exp(W^i_{kt}\theta^{ij})}, \quad i,j = R,U,F \tag{6}$$

where θ^{ij} is a parameter vector. We estimate the system of equations 1 to 6 by maximum likelihood, yielding parameter estimates for $(\beta^i, \delta^i, \theta^{ij}, \sigma^i)$, $i,j = R,U,F$.

We consider several implementations of equations 1 to 6. In our simplest specification, Model (1), we include only a constant term in W^i, X^R and X^U, and we include a constant and the terminal gate price in X^F. This allows us to characterise the basic properties of the price cycle while retaining the dependence of the retail price on the wholesale price in the non-cycling regime. following Noel (2007a,b), we also consider specifications in which we include in the vectors X and W information about station k and the current position in the price cycle. To discuss these specifications, we define two new variables.

We define the variables $position$ and $follow$ analogously to Noel (2007a). $position$ is calculated as $position_{kt} = P_{k,t-1} - tgp_{kt}$, the difference between yesterday's retail price and the terminal gate price available at the nearest terminal gate today. By measuring the retail margin, this variable captures the position in the current cycle. $follow$ is an indicator variable taking the value 1 if the firm has not yet relented in the current cycle (while another nearby station has), and taking the value 0 if the firm has already relented.[15]

In Model (2), we incorporate $position$ in X^U, X^R, and W^U, allowing the size of price changes in the cycle and regime transition probabilities to depend on the stage of the cycle. In Model (3), we include $follow$ in X^R and W^U, allowing the size of the relent and regime transition dynamics to depend on whether a station is following in the current cycle. In Model (4), we include both variables in a single specification. Finally, prices exhibit considerable intrabrand synchronicity, particularly for the major brands. Figure 11 provides an illustrative example. In our empirical work, we adopt a very conservative approach, reporting fully robust standard errors with clustering performed at the brand level.

5 Results

In this section, we consider a range of specifications to describe the nature of the petrol price cycle and its evolution over time. In section 5.1 below, we characterise cycle dynamics using Models (1) - (4) for the year 2003. The year 2003 was relatively uncontaminated by dramatic market events. Consideration of this period thus allows us to characterise a period of relatively consistent price cycles. In contrast to Noel (2007a,b), we find substantial differences between the cycling behaviour of major and independent firms. Accordingly, we break the sample up into separate subsamples and report estimates for each subsample separately. In

[15] More precisely, we designate that a station has relented if they raise price by at least 6 cents in a single day. If a station has not relented within the last 6 days, while another station within a 5km radius has, we ascribe a value of 1 to the follow indicator.

section 5.2, we examine how pricing dynamics have evolved over time and relate this to market developments. To this end, we employ Model (1) for a range of different sample periods. We are unable to estimate our model in periods of major disruption to the cycle. We discuss these episodes in section 5.2.1.

5.1 Characterising the cycle

Table 2 contains estimates of Model 1 for the year 2003. The table is broken up horizontally into information about characteristics of the relenting, undercutting, and focal regimes; and estimated switching probabilities between these regimes. Column 1 contains estimates for the oil majors. Several features stand out. First, results for the undercutting regime suggest that during periods identified as price cycles, firms change prices every day.[16] This contrasts with the specification of MT, where we have argued that the alternating moves specification is a fundamental foundation for Edgeworth cycle equilibria. Notice that the other two classes of Edgeworth cycle theories we discuss in Section 2 do not require alternating moves. In this light, we see this as evidence that additional work is needed to refine the theory of Edgeworth cycles.[17]

Second, in line with the results of Noel (2007a,b), price cycles are highly asymmetric. The relenting phase lasts for a single day in which prices rise by around 10 cents on average. The undercutting phase lasts around 6 days on average, with price falls averaging 1.4 cents per day. There is some transition between the price cycling regimes and the focal regime. In the focal regime, prices are relatively sticky, with no price changes on approximately 70% of days. However, wholesale price changes are ultimately fully passed through to retail prices.

Column 2 of Table 2 contains estimates for independent stations. Pricing dynamics are of a different character for these stations. The relenting phase is less dramatic, with prices rising on average around 3.5 cents per day, and sometimes occurring over more than one day. Notice also that there is greater variability in relenting behaviour; the standard deviation of the price rise is of the same order of magnitude as the mean. In the undercutting phase, prices fall by around 1 cent per day on average. Some price stickiness is also evident with prices remaining unchanged on 11% of days. No transition between the cycling regimes and the focal regime is evident. Essentially then, we can characterise independent stations as either cycling stations or non-cycling stations. For the non-cycling stations, prices are very sticky, with price changes occurring on 7% of days. Ultimately, wholesale price movements are almost fully passed through to retail prices for these stations.

In Tables 3 and 4, we allow cycle dynamics to depend on the current position in the cycle and on the behaviour of each station in the current cycle. Table 3 reports results for major firms. Column 1 contains results for Model (2), in which we incorporate $position$. The

[16] Note that constant prices are occasionally observed for cycling stations. These periods have been endogenously classified into the focal regime. Were these to be reclassified into one of the cycling regimes, this would not alter our basic conclusion that cycling stations change prices on the vast majority of days, in contrast to the specification of MT.

[17] See de Roos (2010) for additional evidence against the timing predictions of the MT model in the Fuelwatch setting.

Table 2: Cycle characteristics, Perth 2003

Model	(1)		(1)	
	Major Firms		Independents	
Relenting regime (R)				
$E(\Delta P \vert R)$	9.665	(0.223)	3.487	(0.466)
σ^R	2.094	(0.100)	4.166	(0.260)
Undercutting regime (U)				
$E(\Delta P \vert U)$	-1.387	(0.109)	-0.970	(0.083)
σ^U	1.080	(0.022)	0.983	(0.053)
$Pr(\Delta P = 0 \vert U)$	0.000	(0.000)	0.132	(0.047)
Focal regime (F)				
Constant	3.204	(5.991)	13.635	(4.059)
Gate price	1.005	(0.053)	0.920	(0.045)
σ^F	3.009	(0.453)	2.981	(0.307)
$Pr(\Delta P = 0 \vert F)$	0.712	(0.049)	0.934	(0.024)
Switching probabilities				
$Pr(R \to R)$	0.000	(0.000)	0.185	(0.034)
$Pr(R \to U)$	0.971	(0.016)	0.815	(0.034)
$Pr(R \to F)$	0.029	(0.016)	0.000	(0.000)
$Pr(U \to R)$	0.106	(0.024)	0.189	(0.007)
$Pr(U \to U)$	0.833	(0.012)	0.811	(0.007)
$Pr(U \to F)$	0.061	(0.035)	0.000	(0.000)
$Pr(F \to R)$	0.109	(0.012)	0.000	(0.000)
$Pr(F \to U)$	0.071	(0.029)	0.001	(0.001)
$Pr(F \to F)$	0.820	(0.095)	0.999	(0.001)
Stations	109		54	
Observations	37 660		16 796	

Notes:

Figures in parentheses are fully robust standard errors, with clustering at the brand level.

position in the current cycle affects both the speed of price movement and regime transition dynamics. If a relent occurs early in the sense that it is near the top of the price cycle, the size of the price rise is reduced. In the undercutting phase, price cuts are more substantial nearer the top of the cycle. Stations are also less likely to transition from undercutting to relenting nearer the top of the cycle. Note that the regularity of the cycle in our data lends another interpretation to these results. If wholesale prices decrease during a cycle, this will increase the retail margin, increasing the likelihood that the next cycle starts later than otherwise, and decreasing the size of the price rise initiating the next cycle. Finally, firms change price every day, no matter what the current position of the cycle, again violating the timing specification of MT.

Column 2 contains results for Model (3), incorporating $follow$. Following stations tend

Table 3: Cycle characteristics, Perth 2003, Major firms

Model	(2)		(3)		(4)	
			Relenting regime (R)			
Constant	10.193	(0.345)	10.271	(0.141)	10.825	(0.276)
position	-0.623	(0.192)			-0.641	(0.191)
follow			-0.988	(0.209)	-1.183	(0.286)
σ^R	1.788	(0.090)	2.011	(0.095)	1.736	(0.043)
			Undercutting regime (U)			
Constant	-0.529	(0.056)	-1.326	(0.051)	-0.517	(0.044)
position	-0.157	(0.011)			-0.158	(0.010)
σ^U	0.958	(0.036)	1.115	(0.031)	0.955	(0.044)
$Pr(\Delta P = 0\|U)$	0.003	(0.000)	0.000	(0.000)	0.003	(0.001)
			Focal regime (F)			
Constant	1.022	(6.716)	1.902	(4.792)	1.173	(3.222)
Gate price	1.036	(0.068)	1.027	(0.051)	1.032	(0.031)
σ^F	3.097	(0.099)	3.112	(0.118)	3.098	(0.051)
$Pr(\Delta P = 0\|F)$	0.724	(0.047)	0.697	(0.048)	0.721	(0.051)
			Switching probabilities			
$Pr(R \to R)$	0.000	(0.001)	0.000	(0.000)	0.000	(0.001)
$Pr(R \to U)$	0.941	(0.022)	0.957	(0.020)	0.939	(0.015)
$Pr(R \to F)$	0.059	(0.021)	0.043	(0.020)	0.061	(0.014)
$Pr(U \to R)$	0.115	(0.008)	0.162	(0.012)	0.135	(0.011)
$Pr(U \to U)$	0.864	(0.013)	0.803	(0.017)	0.840	(0.021)
$Pr(U \to F)$	0.021	(0.011)	0.035	(0.012)	0.025	(0.014)
$Pr(F \to R)$	0.029	(0.029)	0.032	(0.028)	0.018	(0.017)
$Pr(F \to U)$	0.091	(0.021)	0.093	(0.016)	0.099	(0.025)
$Pr(F \to F)$	0.880	(0.047)	0.875	(0.043)	0.883	(0.042)
			Marginal effects			
$\partial Pr(\Delta P = 0\|U)/\partial POS$	0.002	(0.000)			0.002	(0.000)
$\partial Pr(U \to R)/\partial POS$	-0.036	(0.004)			-0.029	(0.004)
$\partial Pr(U \to U)/\partial POS$	0.040	(0.008)			0.028	(0.007)
$\partial Pr(U \to F)/\partial POS$	-0.004	(0.006)			0.001	(0.005)
$\partial Pr(U \to R)/\partial FOL$			0.509	(0.077)	0.283	(0.054)
$\partial Pr(U \to U)/\partial FOL$			-0.556	(0.062)	-0.352	(0.101)
$\partial Pr(U \to F)/\partial FOL$			0.046	(0.017)	0.069	(0.049)
Stations	109		109		109	
Observations	37 660		37 660		37 660	

Notes:
Figures in parentheses are fully robust standard errors, with clustering at the brand level.

to raise prices by about 1 cent less than the leader. That is, they will tend to undercut the price previously set by the leading stations. Further, once a cycle has commenced, following stations are likely to transition quickly from the undercutting to the relenting phase. Finally, Model (4) contains both the position variable and follow indicator, with qualitatively similar results to Models (2) and (3).

Table 4 reports analogous results for independent firms. Consider first Model (2). The relationship between pricing dynamics and the position variable is qualitatively similar to the major stations. Nearer the top of the cycle, price rises are more modest, undercutting is more aggressive, and transition from undercutting to relenting is less likely. Turning to Model (3), following stations are also more likely to transition from undercutting to relenting. Notice, however, that the relationship between the size of the relent and the follow indicator is sensitive to the inclusion of $position$. In Model (3), the size of the relent is considerably greater for following stations. This may be because occasionally independent firms appear to encourage a new cycle by raising price by a small amount. They appear reticent to risk a large price rise, but a smaller price rise could encourage an oil major to start the next cycle. Hence, leading independent firms will sometimes appear to relent by a small amount. However, in Model (4), the size of the relent is reduced for following stations. That is, once we control for the stage of the current cycle, following stations tend to raise price by less than leading stations, in line with the results for major firms.

Taken together, these results paint the following picture of a price cycle. The start of a cycle is signaled by a switch to the relenting phase. Typically, oil majors are the first to relent. Relenting by an oil major takes place in a single day. The following day, the relenter begins to cut prices. Most other firms relent within the next day or two, but by less than the leading firm(s). Once firms have relented, they then proceed to undercut. As firms continue undercutting and the retail price approaches the terminal gate price, the probability of a new relenting phase rises.

The role played by independent firms and oil majors in the cycle is noticeably different. Majors are more likely to be cycle leaders. Major firms also tend to exhibit a cycle of greater amplitude. While they appear reluctant to lead a new cycle through a large price rise, independent firms occasionally raise prices modestly, perhaps to encourage the onset of the next price cycle.

5.2 Cycle variation

In this section, we examine how petrol price dynamics have changed over time. To this end, we harness Model (1), which permits a convenient description of the price cycle. We estimate Model (1) for our full sample of stations for a sequence of overlapping one year sample periods, with each sample period beginning one month later than the last.[18] Notice that this involves 11 months of overlapping data between successive samples, inducing correlation between successive parameter estimates. We estimate using one year samples beginning in the months December 2002 to January 2004, and November 2005 to January 2006. Note that we have trouble identifying our empirical model for the sample periods beginning February

[18] Our first sample is slightly less than one year, commencing on December 19, 2002 and ending on November 30, 2003. Commencement of this sample coincides with the availability of terminal gate prices.

Table 4: Cycle characteristics, Perth 2003, Independents

Model	(2)		(3)		(4)	
			Relenting regime (R)			
Constant	5.771	(0.031)	0.346	(0.617)	6.186	(1.307)
position	-1.016	(0.006)			-0.983	(0.121)
follow			3.879	(0.856)	-0.286	(1.221)
σ^R	3.032	(0.151)	3.868	(0.258)	2.882	(0.085)
			Undercutting regime (U)			
Constant	-0.261	(0.047)	-0.969	(0.087)	-0.274	(0.050)
position	-0.192	(0.005)			-0.196	(0.006)
σ^U	0.829	(0.038)	0.971	(0.051)	0.848	(0.055)
$Pr(\Delta P = 0 \| U)$	0.112	(0.033)	0.129	(0.052)	0.111	(0.043)
			Focal regime (F)			
Constant	10.744	(3.368)	13.423	(4.608)	8.960	(6.836)
Gate price	0.950	(0.036)	0.922	(0.049)	0.970	(0.069)
σ^F	2.751	(0.166)	2.976	(0.277)	2.802	(0.134)
$Pr(\Delta P = 0 \| F)$	0.914	(0.034)	0.934	(0.026)	0.917	(0.030)
			Switching probabilities			
$Pr(R \to R)$	0.213	(0.056)	0.217	(0.041)	0.222	(0.053)
$Pr(R \to U)$	0.787	(0.056)	0.783	(0.041)	0.778	(0.065)
$Pr(R \to F)$	0.000	(0.000)	0.000	(0.000)	0.001	(0.015)
$Pr(U \to R)$	0.121	(0.017)	0.209	(0.013)	0.126	(0.010)
$Pr(U \to U)$	0.878	(0.016)	0.790	(0.013)	0.872	(0.010)
$Pr(U \to F)$	0.001	(0.001)	0.001	(0.001)	0.003	(0.002)
$Pr(F \to R)$	0.001	(0.002)	0.000	(0.000)	0.001	(0.005)
$Pr(F \to U)$	0.001	(0.001)	0.001	(0.002)	0.002	(0.003)
$Pr(F \to F)$	0.998	(0.003)	0.999	(0.002)	0.997	(0.008)
			Marginal effects			
$\partial Pr(\Delta P = 0 \| U)/\partial POS$	0.015	(0.005)			0.014	(0.007)
$\partial Pr(U \to R)/\partial POS$	-0.026	(0.003)			-0.027	(0.002)
$\partial Pr(U \to U)/\partial POS$	0.026	(0.003)			0.027	(0.002)
$\partial Pr(U \to F)/\partial POS$	0.000	(0.000)			0.000	(0.000)
$\partial Pr(U \to R)/\partial FOL$			0.327	(0.027)	0.223	(0.012)
$\partial Pr(U \to U)/\partial FOL$			-0.329	(0.029)	-0.229	(0.015)
$\partial Pr(U \to F)/\partial FOL$			0.002	(0.003)	0.006	(0.008)
Stations	54		54		54	
Observations	16 796		16 796		16 796	

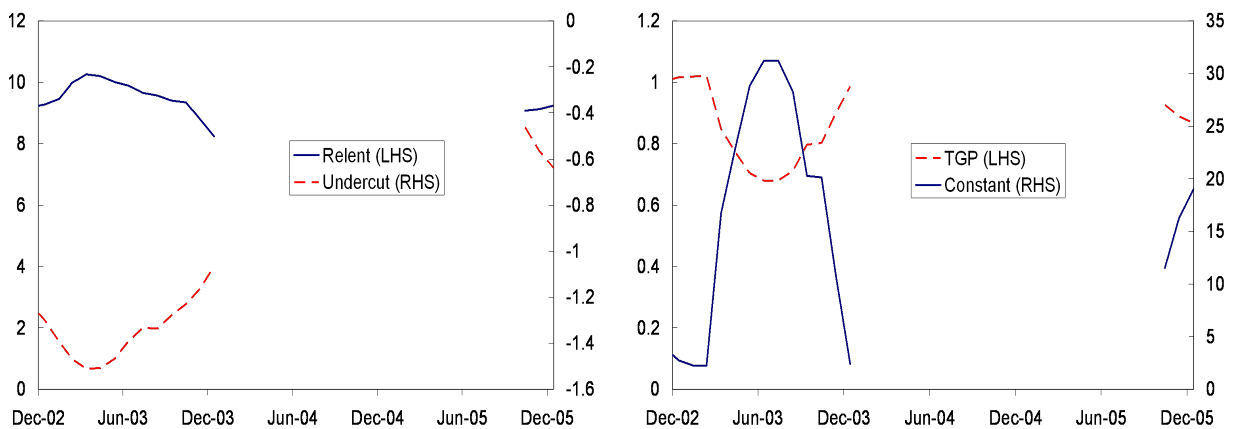
Notes:

Figures in parentheses are fully robust standard errors, with clustering at the brand level.

2004 until the sample periods beginning October 2005. In this time, cycles were disrupted by the entry of Coles Express into the market through the takeover of a large number of Shell stations in March 2004, and the instability in the oil market associated with Hurricane Katrina in September 2005. Consequently, all samples covering the period March 2004 to December 2005 contain data involving disruptions to the cycle. We discuss cycle disruptions in more detail in Section 5.2.1 below.

Figures 5 and 6 present a selection of parameter estimates for these sample periods. Figure 5 presents estimates of the behaviour of prices within a regime. On the horizontal axis of each panel is the first month of the sample period. The left panel contains the estimated average size of price rises (in cents) in the relenting regime (left axis), and price decreases in the undercutting regime (right axis). The most striking feature is the decrease in the size of the average price decline in the undercutting regime, comparing the early samples at the left of the figure with the later samples at the right of the figure. By contrast, the size of the price rise in the relenting regime is relatively stable. This suggests that our observation of Figures 2 and 4 related to station #249 is more general: the length of a cycle has increased over time and the extent of asymmetry between relenting and undercutting phases has become more pronounced. We return to this issue below.

Figure 5: Within-regime behaviour over time

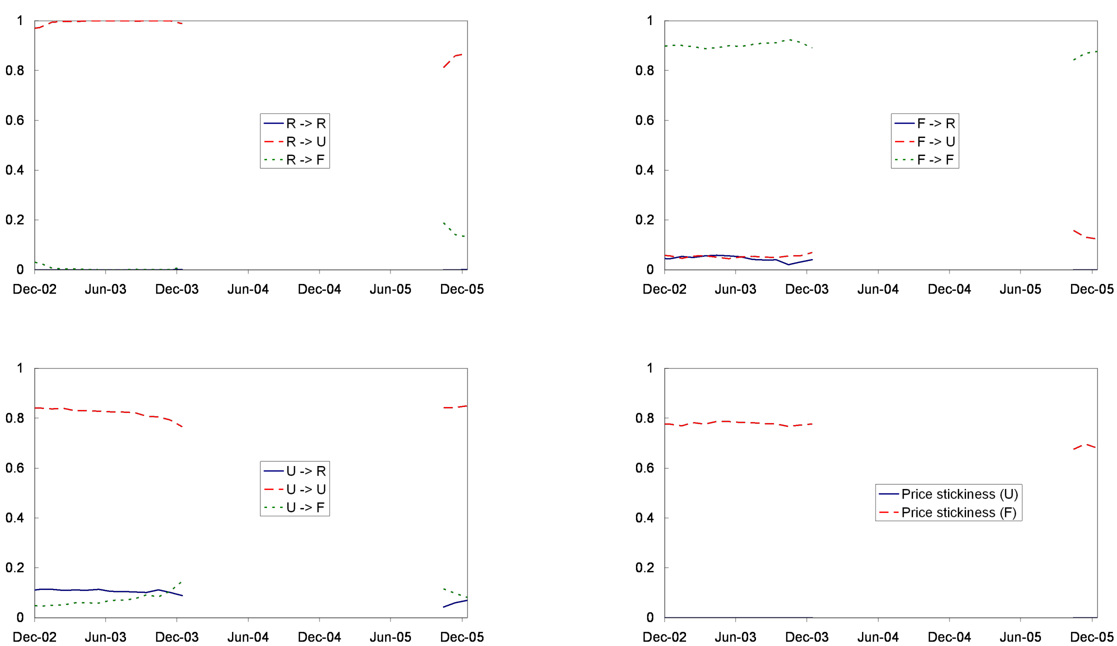


Notes: Vertical axes refer to cents per litre. Horizontal axes refer to the start month of each one year sample.

The right panel contains parameter estimates for the focal regime. Changes in wholesale prices are initially passed through completely to retail prices. The extent of measured pass through dips to around 70% before rebounding. This is likely due to the increasingly erratic nature of pricing behaviour following the entry of the supermarket chains. There are some unsuccessful attempts and half-hearted attempts to maintain price cycles (examples can be seen in the left panel of Figure 4). Some periods of volatile pricing are endogenously assigned to the focal regime, implying reduced sensitivity to wholesale price movements.

Figure 6 documents regime transition dynamics over time. The top left panel shows regime transition probabilities from the relenting regime. For the entire sample, each relenting phase lasts one day. The bottom left panel contains transition probabilities from the undercutting regime. The rate of transition to the relenting regime is lower at the end of the sample, consistent with an increase in the length of a price cycle. There is also increased transition to the focal regime from both relenting and undercutting regimes, suggesting that cycles are interrupted more often later in the sample. This is consistent with the disruptive effect of the entry of the supermarkets. The top right panel shows transition probabilities from the focal regime, and suggests the focal regime is relatively persistent, consistent with an average length of the focal regime of one or two weeks. This is suggestive of a station sitting out a price cycle before rejoining the fun. Finally, the bottom right panel shows the prevalence of sticky prices in the undercutting and focal regimes. There is considerable stickiness in prices in the focal regime. However, firms change prices every day in the undercutting regime throughout the sample, suggesting that the timing assumption of the MT model is unsupported over our entire sample.

Figure 6: Regime transition over time

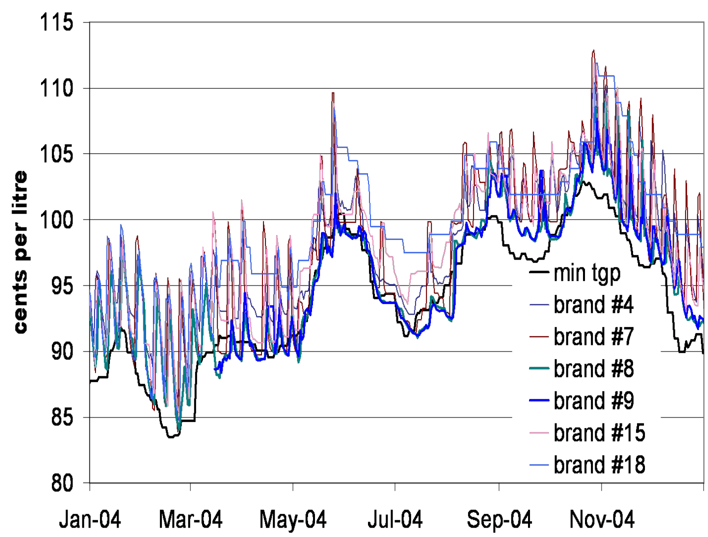


Notes: Vertical axes refer to regime transition probabilities. Horizontal axes refer to the start month of each one year sample.

5.2.1 Cycle disruption and reformation

Two market events disrupted the pattern of price cycles in our sample. In this subsection, we briefly discuss each event in turn. The first event was the large scale entry of Coles Express through the takeover of Shell service stations on March 15, 2004. Figure 7 shows brand average retail petrol prices in 2004 for the oil majors and supermarkets for metropolitan Perth north of the Swan river. The minimum daily terminal gate price (min tgp) is shown by the bold black line; the supermarket brands are the coloured bold lines; and the remaining lines show oil majors. Until the entry of Coles Express, all the oil majors and many independent stations regularly participated in price cycles. Following their entry, Coles Express and their rival supermarket chain, Caltex Woolworths, aggressively undercut the prices charged by the oil majors and independents. In fact, until November 2004, the supermarket chains typically priced below the prevailing terminal gate prices.

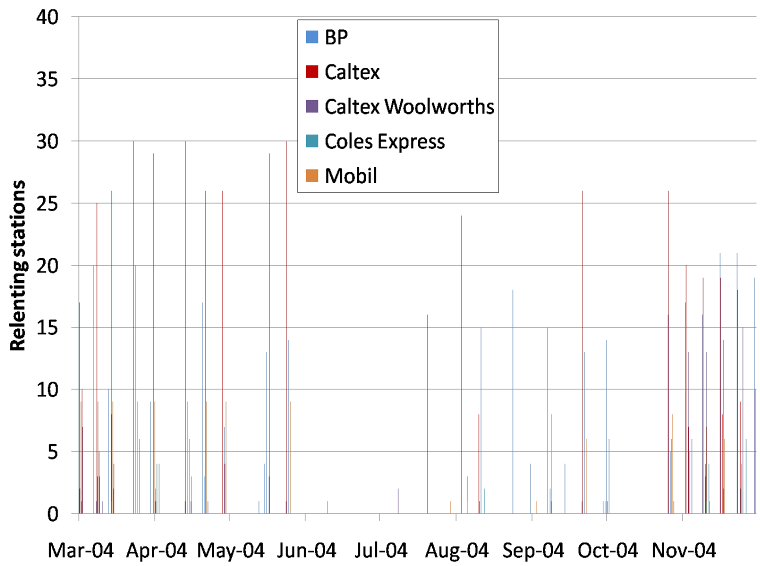
Figure 7: Brand average prices in 2004



The oil majors attempted both to maintain the price cycle in the aftermath of entry, and to reignite the cycle after it had stalled. Figure 8 provides a glimpse into the episode. The figure depicts the number of stations relenting by brand for each day in the period March 1, 2004 to November 30, 2004. To construct the figure, we define a relent as a price rise of greater than 6 cents per litre. In early March, prior to the entry episode, cycles were regular, with participation by all of the oil majors. Immediately following entry, the majors continued to relent relatively frequently, but the frequency of relents declined over time until it essentially ceased by the end of May. In this period, some of the relents were retracted by quickly cutting prices again rather than gradually lowering them in the fashion of an asymmetric price cycle. In the period July to September, the majors made increasingly frequent attempts to reignite the cycle. In November, cycles became regular, with routine participation by both the oil majors and the supermarket chains. By 2006, participation by the supermarket chains in petrol price cycles was entrenched.

It is interesting to note that it is clearly the entrants that persistently undercut the prices of the incumbent firms. Two candidate explanations for this price war stand out. First, it is likely that supermarket chains have an interest in building market share for reasons that go beyond the direct profitability of petrol sales; they wish to induce customers to buy groceries as well. We should also bear in mind that this period corresponds to the adoption of

Figure 8: Relenting behaviour in 2004

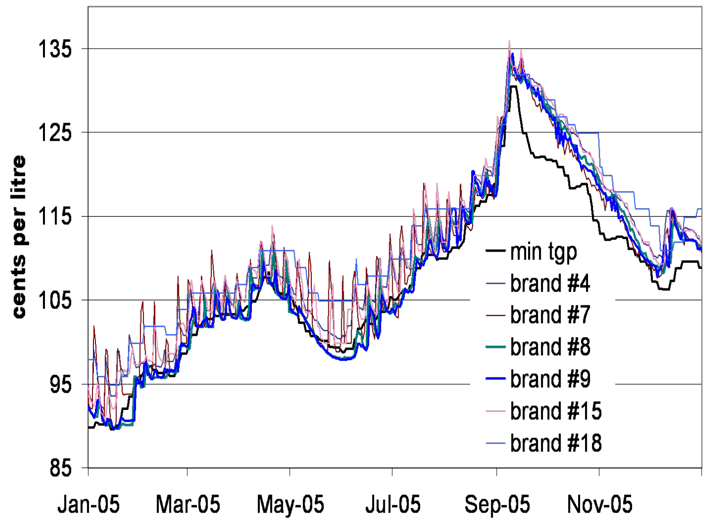


the supermarket "shopper docket" schemes, in which customers purchasing groceries obtain discounts on fuel purchases at associated petrol stations. We may suspect that this is not the full explanation because the price war is temporary, while this motivation seems to be permanent. However, Wang (2010) argues that if bundling is adopted as an advertising strategy, there may in fact be an incentive to engage in short term promotion.

A second related possibility is that the process of gaining market share is a gradual process, hastened by discounting relative to rivals. Supermarkets might then wish to build market share rapidly before settling in to a more benign competitive stance. This explanation is related to the observation of de Roos (2004) that a large scale entrant may have an incentive to behave aggressively to build up market share before adopting a more accommodating competitive attitude. In the example studied by de Roos (2004), the backdrop was the explicit price-fixing cartel of the lysine market. A severe price war took place as the entrant sought to capture market share in advance of a collusive agreement, the terms of which were dependent on the market shares of participants. In the present context, market share inertia is not formalised in a cartel agreement, but it may still be an important consideration.

The second event of interest is Hurricane Katrina in September 2005. Figure 9 illustrates brand average retail petrol prices in 2005 for the Perth metropolitan area north of the Swan River. The September spike in wholesale petrol prices is the most dramatic price rise in our sample. It is perhaps not surprising that price cycles were not maintained during this period of uncertainty and rapidly rising terminal gate prices. There were two relatively shallow cycles at the peak of the wholesale price rise, but price cycles ceased with the subsequent decline in wholesale prices. Petrol retailers appear to have taken advantage of the sustained decline in wholesale prices by only gradually lowering retail prices. Two relatively uncoordinated cycles occurred at the trough of wholesale prices in December, perhaps suggesting attempts to reignite the cycle. This episode compares with a disruption of around 40 days identified for cycling cities in the United States by Lewis (2009).

Figure 9: Brand average prices in 2005

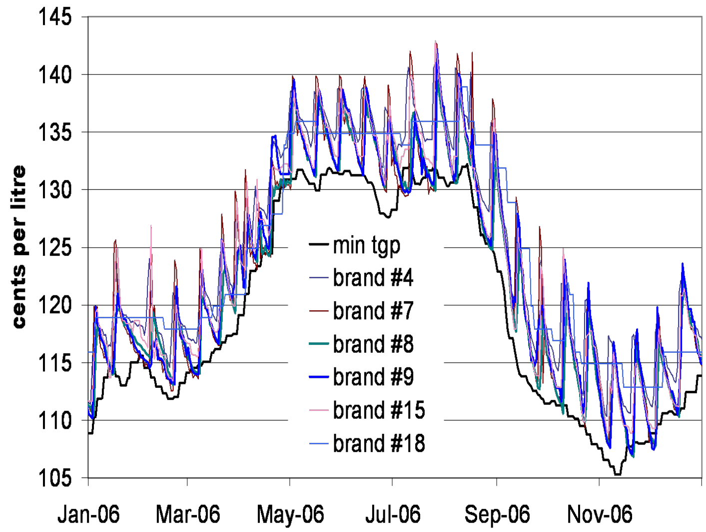


Regular, well coordinated price cycles reemerged in the first week of 2006. Brand average prices for 2006 are depicted in Figure 10. Consistent with the results from our Markov-switching model, most of these cycles lasted approximately two weeks, substantially longer than the price cycles prevailing earlier. The cause of this increase in cycle length is not clear. Price cycles did not lengthen in other metropolitan areas in Australia that were not subject to the Fuelwatch scheme, suggesting a possible role played by the scheme. However, the Fuelwatch program started in 2001 and price cycles did not lengthen until 2006, implying that the scheme is unlikely to be the sole explanation.

Some other developments in the characteristics of cycles may shed some light on the issue. First, the supermarket chains participate fully in the price cycles in 2006; their participation had been muted and sporadic until this time. Second, the leadership pattern of price cycles has changed over time. In 2003, the relenting phase was typically initiated by one or a combination of the oil majors BP, Caltex or Shell, and occasionally by Mobil. following the takeover of a large number of Shell stations by the supermarket chain Coles Express in 2004, Shell was no longer a cycle leader, but the other oil majors continued to play a leadership role. In 2006, BP became the only oil major to play a consistent leadership role, with the supermarket stations occasionally also leading. This has some bearing on the conclusions of Wang (2009b). Wang argues that the adoption of mixed strategies to resolve the war of attrition at the bottom of the cycle is evidence in favour of the MT model of price cycles. However, it appears that the adoption of mixed strategies to resolve the war of attrition is not a robust feature of the data.

Figure 11 illustrates the change in leadership patterns. The left panel shows the number of BP and Caltex stations relenting each day for the first half of 2003 for the region of metropolitan Perth north of the Swan river. For purposes of illustration, we define a relent

Figure 10: Brand average prices in 2006



as a price rise of greater than 6 cents. The right panel shows analogous information for the first half of 2006. In 2003, there is no clear bilateral leadership pattern between BP and Caltex. Further, there is a striking degree of intra-brand synchronicity in relenting behaviour. By contrast, in 2006 BP consistently relents before Caltex.[19] In addition, the synchronicity of the BP stations is noticeably reduced.

These observations lead to a potential explanation for the lengthening of the cycle. After the sustained aggressive pricing behaviour of the supermarkets chains in 2004 and 2005, most of the oil majors were no longer willing to lead the price cycles in 2006.[20] BP found itself in the leadership position most of the time (with the occasional participation by supermarkets).[21] Bearing this leadership burden, BP may then have been more reluctant to initiate cycles quickly. With slower cycles, BP is exposed as the leader less frequently, limiting its market share loss. The partial desynchronisation of BP stations could be a reflection of its reluctance to be exposed as the sole price leader. By relenting with a subset of stations, the signal to begin a new cycle is provided while limiting the exposure of BP to market share loss. Finally, it is worth noting that (along the lines argued by Wang (2009b)), price leadership is more costly in the discrete time environment we consider in WA. We are not aware of a corresponding increase in cycle length in other metropolitan areas in Australia that are not subject to this timing restriction.[22]

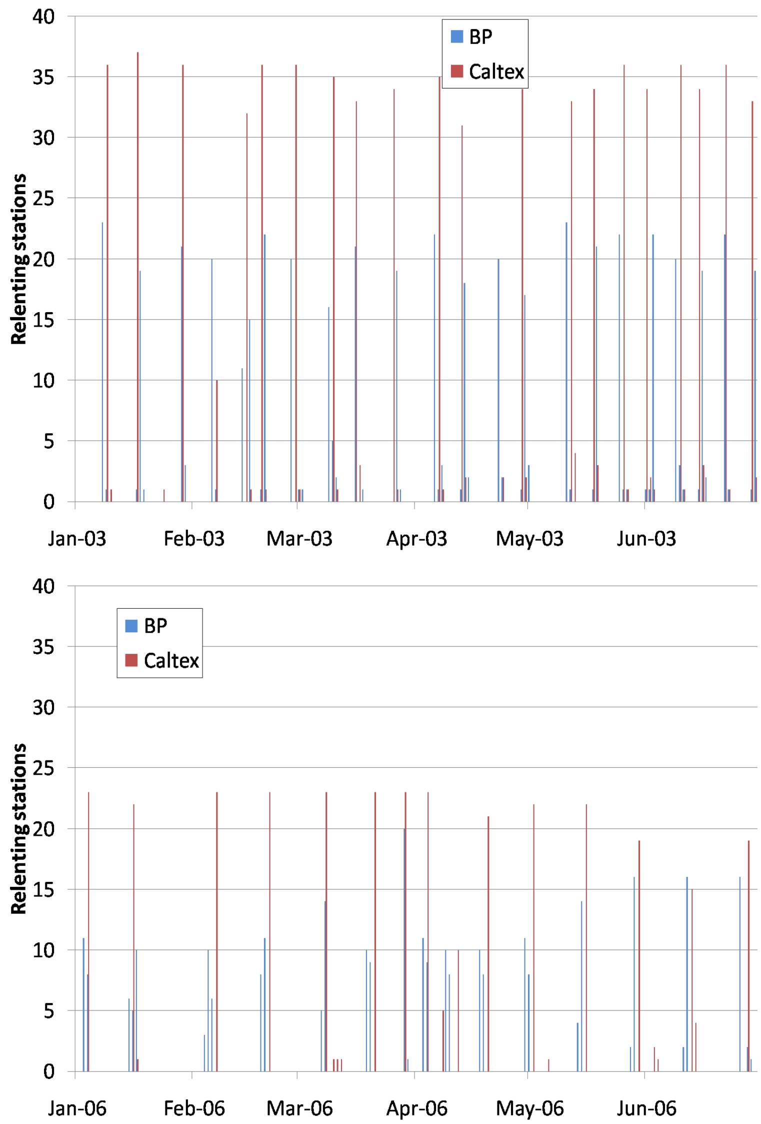
[19] The one apparent exception in April 2006 is actually an example of Caltex relenting very late in the previous cycle.

[20] Industry experts suggest that a media policy to highlight the identity of the leader may have also played a role.

[21] Of course, an alternative explanation is that the petroleum retailers collectively decided that BP should play the role of price leader.

[22] Industry sources confirm that after our sample period, more recent price cycles in Perth are again one week in duration. Nevertheless, these motivations may have played a part in the (ultimately unsuccessful)

Figure 11: Relenting behaviour in 2003 and 2006



6 Conclusion

In this paper, we exploit a unique policy context to study retail petrol pricing dynamics over an extended time frame in an imposed discrete time environment. We quantitatively characterise regular price cycles. The price cycles are substantial, frequent, and highly asymmetric. Independent and major firms play a distinctly different role in the cycle. Major firms lead the relenting phase of the cycle, while independent firms not only follow, but participate in

experiment with a two week cycle.

a muted version of the cycle.

The policy environment permits us to observe the precise timing of all pricing decisions. An important feature of our data is that firms adjust prices in each period of a price cycle. By contrast, asynchronous pricing is a fundamental aspect of the leading theory of retail price cycles due to MT. This suggests that an alternative mechanism for the Edgeworth cycle may be present in our setting, and leaves open the possibility that we need to refine our understanding of Edgeworth cycles more generally.

We also detail cycle interruptions and changes in the character of the cycle. The entry through takeover of two major supermarket chains led to a prolonged disruption of the cycle. Attempts to reignite the cycle by oil majors were thwarted by persistent undercutting by the entrants. Finally, after a further market disruption associated with Hurricane Katrina, the supermarket chains became full participants in the cycle nearly two years after their entry. An increase in the duration of the price cycle in the latter stages of our sample is plausibly due to a combination of an increase in the number of full cycle participants and a change in leadership patterns. A single firm became the regular price leader and likely has a preference for a slower cycle to mitigate the costs of providing price leadership. In this regard, the timing restrictions imposed by policy changes may also have played a role by accentuating the costs of leadership.

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