Negotiating Price Coordination: A Study in Retail Gasoline*

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Abstract

This paper studies the role that market prices can play in the coordination and renegotiation of market outcomes. We examine a gradual, sometimes disruptive, equilibrium transition with these features using a unique dataset of daily station-level prices from an urban gasoline market. Aided by an information-sharing platform, the firms transition over seven years from one pricing structure with focal pricing rules to another through price signaling. Along the path, we find recurrent cheating on focal pricing rules without punishment and uncover a price war involving renegotiation and resolution. These results establish that prices can yield a sufficiently rich communication medium for implementing and renegotiating collusive pricing structures. We discuss implications for theories of collusion in economics and policies for detecting and prosecuting cartels.

JEL Classification: D22, D43, D83, L13

Keywords: Negotiation; Collusion; Information sharing; Digital platform

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1 Introduction

Collusion research dating to Stigler (1964) underlines the importance of communication in cartels. In the "smoke-filled rooms" that our theories envisage, colluding firms explicitly devise collusive arrangements that spell out many things: who increases prices when, how to respond to fluctuations in demand and cost, how to detect cheating, and what to do if cheating occurs. If firms face incomplete information on variables such as prices, collusion can break down occasionally, but firms' arrangements spell out how to renegotiate and resolve conflicts to ensure cartel stability (Green and Porter, 1984). Extensive evidence from explicit cartels underlines the importance of renegotiation in facilitating collusion.[1]

Given collusion's inherently complex and contingent nature, human language has long been presumed to be the communication medium among firms (Harrington, 2017). Building from this presumption, antitrust policies for detecting and prosecuting cartels focus on identifying explicit communication and agreements. Yet, with the rise of digitization, decentralized information sharing online, and centralized information sharing through third-party "data analytics" providers, policymakers are increasingly asking: do digital platforms provide modern "smoke-filled rooms" to facilitate collusion?[2] If so, current antitrust laws and policies targeting collusion that focus on explicit agreements are potentially not well-equipped to address systemic collusion from platform-enabled communication (Ezrachi and Stucke, 2017).

Recent evidence on digitization and collusion gives credence to these concerns. Researchers have indeed found firms can use platforms to implement collusive outcomes (Borenstein, 2004; Byrne and de Roos, 2019; Byrne et al., 2024a). Platform-enabled pricing algorithms have similarly been found to facilitate equilibrium transitions that enhance profit margins to the detriment of consumers (Assad et al., forth).[3]

In this paper, we establish that prices are a sufficiently rich communication medium to enable negotiation over anticompetitive arrangements among platform-enabled firms. That is, we show that firms can use prices to implement collusive pricing structures *and* negotiate over the pricing structures themselves. In effect, our analysis implies that price-based communication is closer to language-based communication than previously understood: both can facilitate renegotiation over collusive pricing structures, which is valuable for establishing collusive arrangements and maintaining their long-run vitality.

[1] See Levenstein and Suslow (2006a) or Marshall and Marx (2012) for overviews of case studies and evidence on renegotiation in explicit cartels.

[2] See, for example, Chapter 7 of Council of Economic Advisers (2023) for discussion surrounding this question. For specific examples around platform-enabled collusion, see Department of Justice complaints with RealPage (2020) and Agristats (2023) in which digital platforms enable collusion in real-estate and meat processing.

[3] See also Calvano et al. (2020), Musolff (2022), Asker et al. (2020), Leisten (2022), and Brown and MacKay (2023).

Overview. We develop these insights in the context of an urban retail gasoline market that experiences a remarkable seven-year equilibrium transition involving coordinated pricing, price wars, and renegotiation. Our analysis uses complete, high-frequency station-level price data from a third-party platform that enables near-real-time information sharing among oligopolists in the market that we study. The context is particularly well-suited for analyzing collusion, as revealed by a federal antitrust case after our sample period charging the platform and the firms with facilitating and engaging in anticompetitive conduct. We describe the research context and our data in Section 2.

In Section 3, we provide a high-level description of the equilibrium transition. We document the existence of two coordinated pricing structures. At the start of our sample, firms use price leadership and focal rules to coordinate price setting week-to-week. However, by the end of our sample, focal rules disappear, and firms use price signaling to coordinate.

Motivated by these preliminary results, Section 4 develops a forensic analysis of the pricing structure's evolution. We uncover four distinct phases in the transition. In the first phase, after years of stability, the firms' focal pricing rule begins to evolve in response to repeated cheating by subsets of firms. As we show, such cheating substantially undercuts rivals' prices week-to-week. The cheaters' identity—retailers who jointly run gasoline and grocery businesses with tied fuel-food discounts—points to a key asymmetry in the market. The cheaters disproportionately benefit from grocery sales by offering low gasoline prices. Such asymmetry gives the cheaters leverage in bargaining over the pricing structure.[4]

Although the cheating is blatant, the negatively affected (non-grocery) firms do not implement punishments. Instead, they gradually accommodate cheating, evolving the focal pricing rule over six months and re-establish coordination with the cheaters. The lack of punishment and gradual accommodation reflects a key limitation of evolving coordination. Without explicit communication, firms cannot define punishment rules, which creates scope for rivals to test and learn about the costs and benefits of defection.[5]

The second phase of the transition involves a three-month price war. The same rivals who cheat on focal pricing rules in phase one begin cheating in a similar fashion on the updated focal pricing rule at the start of phase two. This time, however, cheating is met with swift retaliation, causing coordination to break down and prices near wholesale costs. The lack of ac-

[4] Clark and Houde (2013) document similar asymmetry and bargaining effects in an explicit gasoline cartel. As in our setting, they find that the cartel was forced to evolve its pricing rule to ensure incentive compatibility among gasoline retailers that offer tied grocery store fuel discounts.

[5] These results connect to Genesove and Mullin (2001)'s analysis of The Sugar Institute and finding of unpunished cheating in an explicit cartel. In their case, cheating is not met with immediate punishment as the cartel "holds court" to establish whether a cheating firm knowingly defected on the collusive arrangement. In our setting, cheating is unambiguously blatant as firms have near-perfect price monitoring through a platform, and the defection we document creates substantial price cuts among defecting firms.

commodation for cheating and speed with which coordination breaks down reveals learning and adaptation by the non-cheating firms. Exploiting the richness of our data, we further show that, in attempting to resolve the war, two major retailers (one grocer, the other non-grocer) signal a desire to implement two distinct (new) focal pricing rules. These negotiations over which rule to implement end at a standstill, and the rivals return to coordinating prices using the focal rule that existed at the start of the war.

A third phase begins after the war, where the focal rules completely unravel. As with the previous two phases, asymmetric retailers with grocery chains repeatedly cheat on focal rules, and their rivals repeatedly attempt to re-establish them. The sheer length of time such cheating is met without punishment—18 months—further speaks to the challenge of implementing collusion without explicitly defining punishment rules and resolving strategic uncertainty. That the grocery-based retailers continually cheat and substantially undercut prices speak to their asymmetric incentives to enhance grocery demand through low gasoline prices.

This brings our forensic analysis to the final phase of the equilibrium transition. In the face of recurrent cheating, non-grocer retailers abandon focal pricing rules altogether. The retailers implement a new pricing structure that requires retailers, including grocers, to signal intent to increase prices whenever price levels get too close to wholesale costs. Compared to focal rules, we show that this evolution in the pricing structure limits retailers' exposure to cheating in coordinating price increases and requires ex-ante costly signals from all retailers in the market before raising prices. The retailers transition to this signal-then-consolidate pricing structure in the final three years of our sample period, and we know from related work that the pricing structure remains stable beyond our sample period (Byrne et al., 2024a).

Section 6 summarizes our findings and discusses some implications. Our findings help inform theories of collusion and the design of data-driven screens for detecting agreements. For antitrust policy, we discuss potential adjustments to antitrust laws for prosecuting anticompetitive conduct stemming from price-based agreements.

Related literature. As mentioned, our primary contribution is to collusion research. It bridges work on tacit and explicit collusion by establishing that price-based negotiation over profit-enhancing pricing structures is possible. Such negotiations parallel how explicit cartels negotiate collusive arrangements using human language. However, our finding of persistent cheating and limited punishment sheds new light on the challenges of collusion absent explicit communication. Nevertheless, our results show that firms can use price-based communication to resolve price wars and transition to different pricing structures. In this way, our results complement existing research on collusive pricing structures.[6]

[6] Borenstein (2004)'s classic study of the Airline Tariff Publishing Company from the United States in the 1990s

More broadly, our results connect to economic research into communication, coordination, and conflict. Substantial work in economic theory establishes when and how communication, including cheap talk, can enable coordination and help resolve conflict.[7] Whereas all of this work focuses on language as a coordinating device, we extend the communication domain to prices, which can create a "meeting of minds" among players to coordinate on collectively better outcomes (i.e., higher profits). Our results also add to scant empirical evidence illustrating how communication can facilitate coordination and stem bargaining breakdown (Backus et al., 2023), complementing a substantial body of evidence from lab experiments.

We also connect to previous empirical research on the retail gasoline industry, especially work on collusive price leadership, signaling, and focal pricing (Borenstein and Shepard, 1996; Wang, 2009; Lewis, 2012, 2015; Byrne and de Roos, 2017; Luco, 2019; Lemus and Luco, 2021; Assad et al., forth; Byrne et al., 2024a) and explicit cartels (Erutku and Hildebrand, 2010; Clark and Houde, 2013, 2014). Our focus on bargaining over the structure of a collusive relationship significantly differentiates our paper from this earlier work.

2 Context and data

Our research context is the retail gasoline market in Melbourne, Australia, from 2007-2014. Over this period, the city has approximately four million people. As is common in retail gasoline markets worldwide, Melbourne has an asymmetric market structure with a handful of dominant retailers, various small retail chains, and smaller chains and independently-run stations.[8] Five dominant retailers – BP, Caltex, Coles, Woolworths, and 7-Eleven – operate approximately two-thirds of the stations in the market. These retailers' station shares are stable over the sample period.[9] The dominant retailers largely set station-level prices centrally, whereas independent

provides a case study into platform-enabled price signalling among airlines. Aryal et al. (2022), who also study the U.S. airline industry, similarly establish that firms can signal and coordinate on capacity reductions through quarterly earnings announcements as required by the Securities and Exchange Commission. Our own work on retail gasoline in Byrne and de Roos (2019) and Byrne et al. (2024b) also reveals the existence of platform-enabled price signaling. For empirical research on non-platform-based coordination involving price leadership, focal points, or signaling, see Busse (2000), Cramton and Schwartz (2000), Knittel and Stango (2003), Wang (2009), Lewis (2012), Ciliberto and Williams (2014), Lewis (2015), Aryal et al. (2022), or Miller et al. (2021).

[7] See Farrell and Rabin (1996) for an overview of earlier theoretical and experimental research on communication and coordination. Crawford (2017) overviews more recent research on these topics. Applications motivating this literature abound, including civil war, voting, public good provision, collective bargaining, and bank runs.

[8] This section summarizes facts derived from detailed annual gasoline industry monitoring reports from the Australian Competition and Consumer Commission (ACCC), specifically ACCC (2008, 2009, 2010, 2011, 2012, 2013, 2014).

[9] The only ownership change of note is 7-Eleven's acquisition of Mobil's retail gasoline station network in 2011. In Melbourne, 7-Eleven's station share increases from approximately 8% to 12%.

station managers set prices on-site.[10] BP and Caltex are vertically integrated gasoline companies and offer loyalty programs associated with national airlines and supermarkets. Coles and Woolworths are the largest two supermarket retailers in the country and offer gasoline price loyalty discounts for shopping in their grocery stores. 7-Eleven operates a chain of convenience stores but is without a loyalty program.

Supply-side information sharing is an important aspect of market structure. Over the sample period, the five major retailers are subscribers to a third-party information-sharing platform from an international data analytics company called Informed Sources.[11] Platform subscribers: (1) provide station-level price data at 15 or 30-minute frequencies, and (2) gain access to this information for all other subscribers. This information sharing occurs strictly among the five major retailers and is unavailable to non-subscribers (i.e., smaller independent stations) or consumers.

A federal antitrust case centering on Informed Sources provides an important piece of context for our analysis. In August 2014 (i.e., after our sample period), the ACCC brought a case against Informed Sources and the five major retailers for anti-competitive conduct. Paraphrasing, the ACCC alleged that the retailers used the Informed Sources platform as a communication device to coordinate in price setting and substantially lessen competition. In its press release,[12] the government explicitly called out price leadership and signaling as underlying mechanisms:

> "*The ACCC alleges that fuel retailers can use, and have used, the Informed Sources service as a near real time communication device in relation to petrol pricing. In particular, it is alleged that retailers can propose a price increase to their competitors and monitor the response to it. If, for example, the response is not sufficient, they can quickly withdraw the proposal and may punish competitors that have not accepted the proposed increased price.*"

As we will see, these comments from the agency foreshadow various aspects of our empirical analysis of the firms' pricing structures below.[13]

Beyond the *Informed Sources* case, there are no other price-fixing cases within our sample period. This may, in part, reflect intensive antitrust scrutiny year-to-year. In particular, the ACCC publishes detailed annual industry monitoring reports dating to 2008, near the start of our primary sample period. None of these reports, nor the federal *Informed Sources* case, unveil

[10] There are some "branded" independent stations for BP and Caltex in the market with on-site price setting, but with price guidance from the major retail brands.

[11] https://informedsources.com/.

[12] The ACCC's August 20, 2014 press release for the case can be found at https://www.accc.gov.au/media-release/accc-takes-action-against-informed-sources-and-petrol-retailers-for-price-information-sharing.

[13] After a 16-month investigation, the parties settled the case. Byrne et al. (2024b) describes the case settlement in detail and empirically evaluates the impact of case remedies on prices, margins, and profits.

Table 1: Summary Statistics

	Mean	Std. Dev.	Min	Max
Prices (cpl)				
Price	134.1	12.7	92.5	190.0
Terminal Gate Price	127.3	12.0	93.4	158.4
Margin	7.1	5.1	-22.1	45.8
Panel Dimensions				
Dates		2,558		
Stations				
BP		132	(17%)	
Caltex		97	(12%)	
Coles		123	(15%)	
Woolworths		97	(12%)	
7-Eleven		83	(10%)	
Other		262	(33%)	
Total		794	(100%)	
Observations		1,581,703	(100%)	

Notes: Sample period is January 1, 2007 to January 1, 2014. Retail prices are at the station-date level. Wholesale Terminal Gate Prices (TGPs) are at the daily level from Melbourne's gasoline terminal gate. Margin is a station's retail price less Melbourne's TGP on a given date.

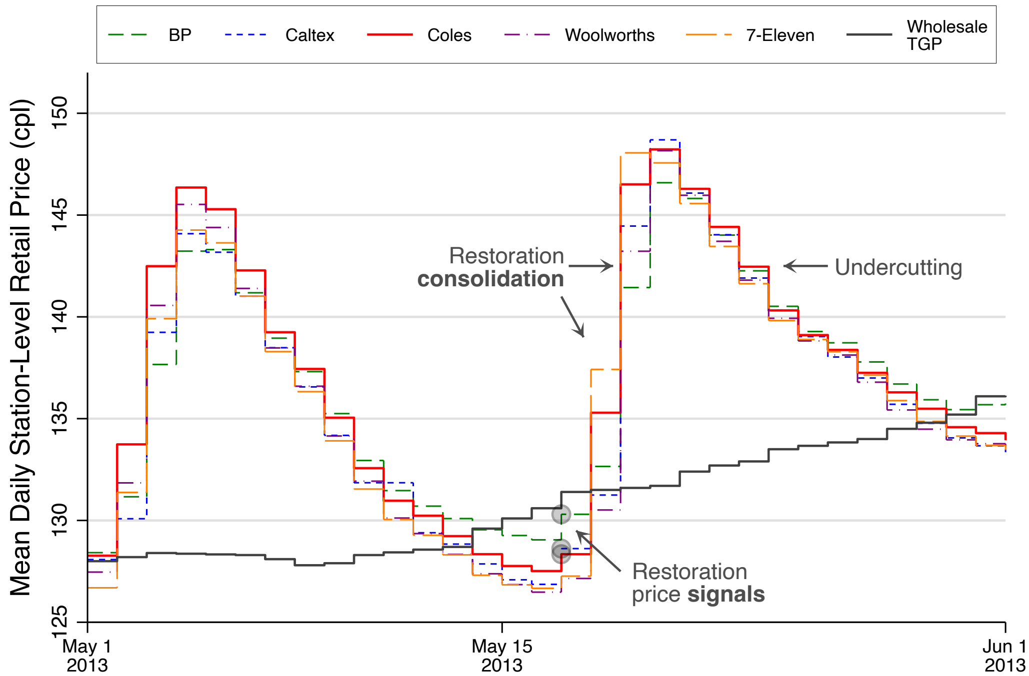
explicit price fixing between the retailers at any point.

2.1 Data

Our analysis uses daily station-level price data for Melbourne from Informed Sources from January 1, 2007 to January 1, 2014. We complement this with Melbourne's daily wholesale terminal gate price (TGP) from the Australian Institute of Petroleum.[14] The wholesale TGP is the main time-varying component of firms' day-to-day marginal cost, with daily fluctuations driven by world oil prices. Thus, the margin between stations' retail prices and the wholesale terminal gate captures station profitability changes over time. Table 1 presents summary statistics for the sample. On average, stations earn a 7.1 cents per liter (cpl) price-TGP margin, which represents a 5.5% markup over the average TGP.

[14] https://www.aip.com.au/.

Figure 1: Retailer-Level Price Cycles



Notes: The figure shows mean daily station-level retail prices for each major retailer between May 1, 2013 and June 1, 2013, computed from daily-station level prices from Informed Sources. The wholesale Terminal Gate Price (TGP) corresponds to the daily wholesale price for unleaded 91 gasoline from Melbourne's local terminal gate from the Australian Institute of Petroleum.

3 An equilibrium transition

In this section, we present a seven-year equilibrium transition in the market. Motivated by this finding, we forensically investigate underlying behavioral mechanisms in Section 4.

3.1 Price cycles

As in many urban gasoline markets worldwide (Eckert, 2013; Holt et al., 2024), Melbourne's market exhibits a regular price cycle. Figure 1 presents example cycles from the latter part of our sample period, from May 1, 2013, to June 1, 2013. Here, we plot daily average prices by retailer; however, analogous cycles exist at the station level. The price cycles exhibit two distinct phases. The *restoration* phase involves large and infrequent price increases that restore profit margins. In the figure, prices increase by 15–20% from the bottom to the top of the cycle during the restoration phase. Between price restorations, firms engage in an *undercutting* phase whereby prices are repeatedly undercut day-to-day. Undercutting continues until prices approach the wholesale TGP and margins go to zero, sparking another restoration.

Figure 1 further shows how price restorations (can) entail a two-part *signal*-then-*consolidate* process. As highlighted in the figure, the small increases in daily average prices at the bottom of the cycle correspond to small subsets of stations restoring their prices. Such price adjustments *signal* retailers' willingness to restore prices and restoration price levels. In light of the signals, average daily prices subsequently increase by 15–20% as retailers restore prices across their station networks, *consolidating* a restoration.

For our analysis of equilibrium transition, where the underlying cyclical pricing structure evolves over time, it is helpful to classify price restorations at the station and market levels. We use the following definitions:

Definition 1.

(i) *A station-level price restoration* occurs on date t if three conditions hold:

1. $p_{it} > p_{it-1}$
2. $p_{it} = \max\{p_{it-5}, \ldots, p_{it+5}\}$
3. $p_{it} - \min\{p_{it-3}, \ldots, p_{it}\} \geq 10$.

(ii) *A station-level price cycle* begins with a station-level price restoration. We enumerate this as "Day 0" of a station's cycle. Cycle days $1, 2, \ldots$ follow as the undercutting phase until the next station-level price restoration occurs.

(iii) *A market-level price restoration* occurs on date t if three conditions hold:

1. $\bar{p}_t > \bar{p}_{t-1}$
2. $\bar{p}_t = \max\{\bar{p}_{t-5}, \ldots, \bar{p}_{t+5}\}$
3. $\bar{p}_t - \min\{\bar{p}_{t-3}, \ldots, \bar{p}_{it}\} \geq 10$,

where $\bar{p}_{it}$ is the mean price across all stations on date t.

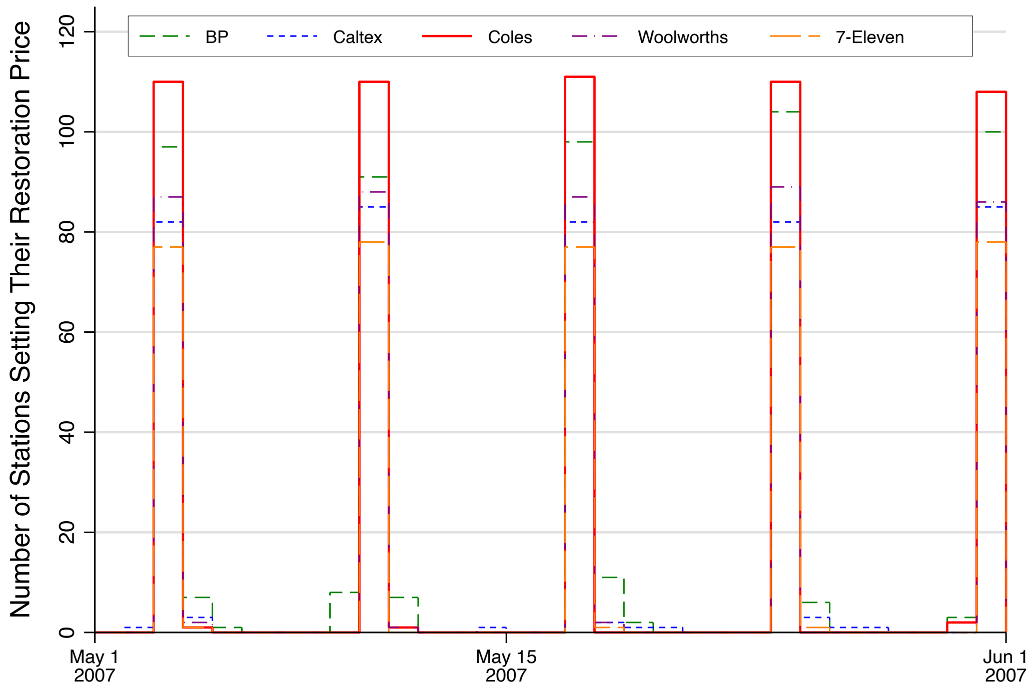
(iv) *A market-level price cycle* begins with a market-level price restoration. We enumerate this as "Day 0" of a station's cycle. Cycle days $1, 2, \ldots$ follow as the undercutting phase until the next market-level price restoration occurs.

These definitions robustly identify station-level and market-level restorations. Our results throughout are robust to the thresholds we use for classifying restorations.[15]

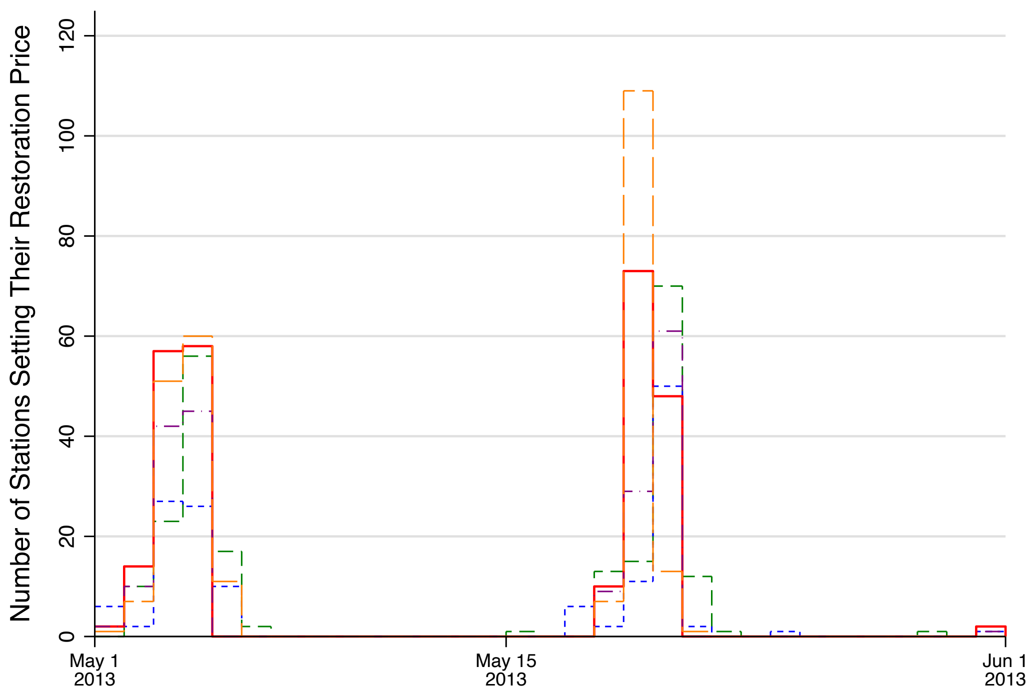
[15] Holt et al. (2024) show rule-of-thumb threshold-based rules for restoration event classification are robust in markets with stable price cycles such as urban Australian markets.

Figure 2: Pricing Structures at the Start and End of the Sample

(a) Station-Level Restorations by Retailer and Date: **May 2007**



(b) Station-Level Restorations by Retailer and Date: **May 2013**



Notes: The figures plot counts of station-level restorations by retailer and date per Definition 1(i) in May 2007 (start of the sample) and May 2013 (end of the sample).

3.2 Two pricing structures

Before delving into the transition, we describe its start and endpoint, which reveal stark differences in restoration phases. In panels (a) and (b) of Figure 2, we plot the number of station-level restorations by retailer and date in May 2007 and 2014. Two key patterns stand out. First, in panel (a), restoration timing is regular at the sample's start. Indeed, the spikes in station-level restorations in panel (a) are all on Thursday, implying one-week cycles. In contrast, in panel (b), market-level restoration events are not weekly, and cycles are longer. By the sample's end, the timing of market-level restorations becomes far less regular.

Second, panel (a) reveals extraordinary coordination in the timing of one-day station-level restorations among all five retailers at the sample's start. There are few station-level restorations on other days of the week, and there is no evidence of the signal-then-consolidate structure from Figure 1. One interpretation of these preliminary patterns is Thursdays serve as an effective *focal* restoration day in coordinating actions, effectively consolidating restoration without any signaling. Panel (b) yields a very different picture at the sample's end. The signal-then-consolidate pricing structure is present, with a small number of stations ($\approx$ 5-10) for each retailer engaging in restorations before restoration consolidation, mainly occurring over two days. Restorations are, however, less rapid than the examples in panel (a) with focal restoration days and weekly cycles.

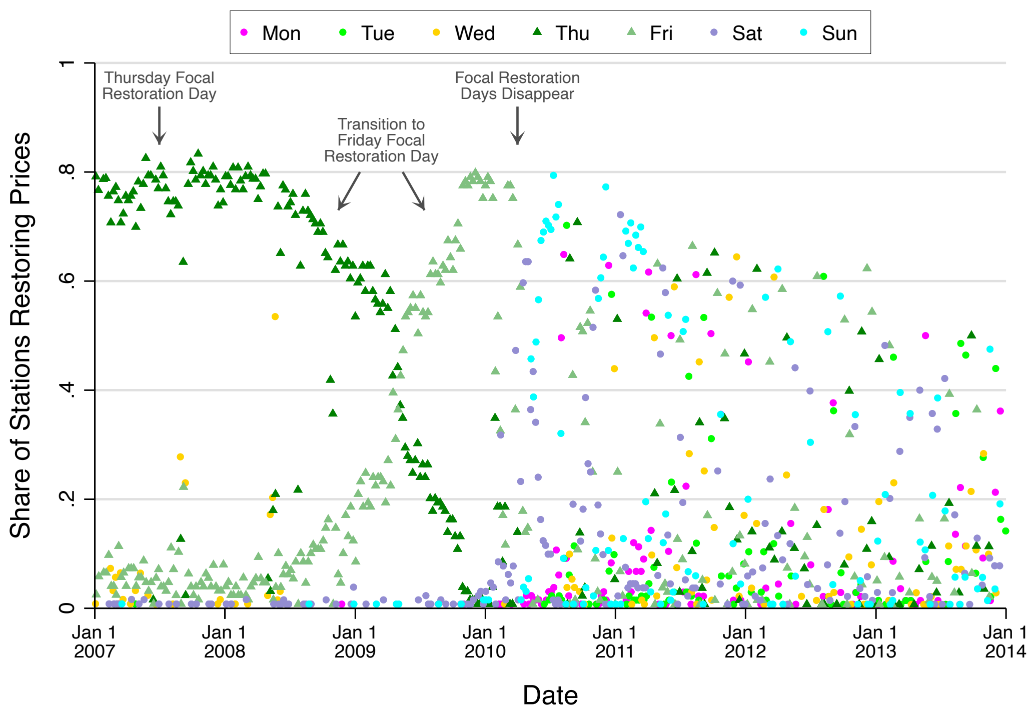
3.3 The collapse of focal pricing rules

Building from the snapshots in Figure 2, we describe the evolution in the timing and coordination of restorations between 2007 and 2014 in Figure 3.[16] In this graph, we plot the daily share of BP stations engaging in restorations by day of the week over our sample period. Consistent with Figure 2(a), between January 2007 and July 2008, Thursday restorations is a stable focal pricing rule.[17] From this point, an 18-month equilibrium transition occurs as the market transitions from Thursday to Friday focal restoration days. Then, starting in March 2010, focal restoration days disappear, and restorations occur across all days of the week. At first blush, this

[16] Figure A.1 in Appendix A analogously plots the evolution of firms' pricing structures for Caltex, Coles, Woolworths, and 7-Eleven. The same patterns emerge as in Figure 3, underlining that our sample contains an equilibrium transition among oligopolists.

[17] Thursday restorations are a stable focal pricing rule dating to July 2005, which is the earliest date we have Informed Sources daily station-level price data for. We use a January 2007 sample start date for brevity and to improve the visualization of our figures. We observe slightly less than 100% of BP stations engaging in restorations week-to-week, reflecting that there are BP-branded independent stations on the periphery of the urban market that do not engage in price cycles. Recall from Section 2 Caltex has similar "branded independent" station types yielding similar patterns to BP. Coles, Woolworths, and 7-Eleven, without "branded independent" stations and centralized price settings, see virtually all their stations engaging in price restorations on Thursdays before July 2008.

Figure 3: BP Station-Level Restoration Rates by Day of the Week



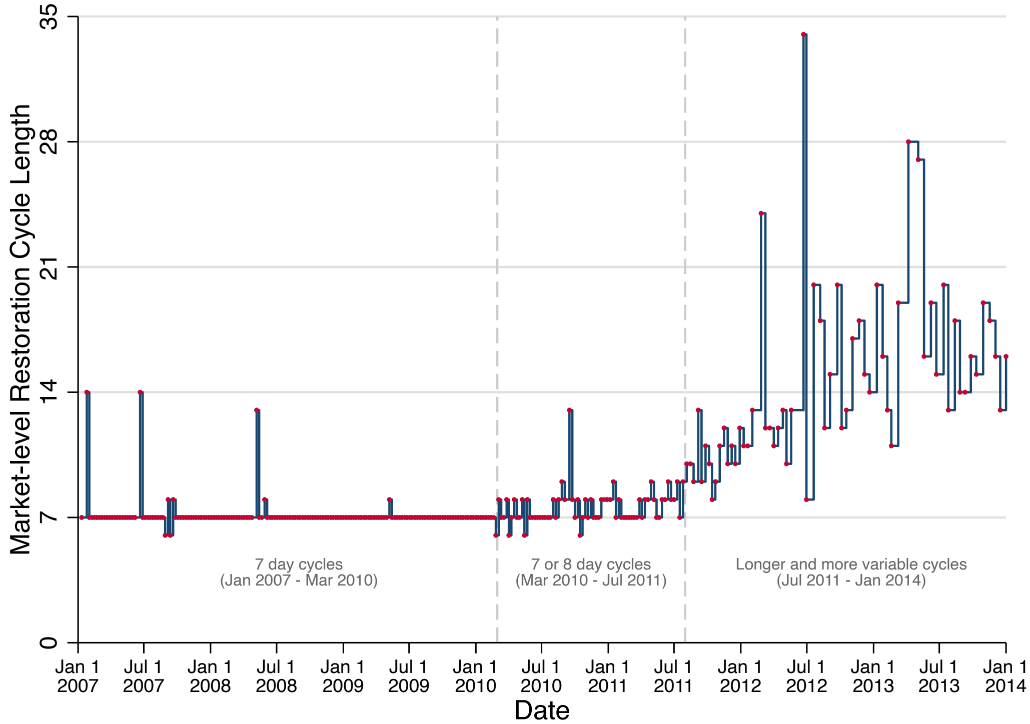
Notes: The figure plots the share of BP stations engaging in station-level price restorations per Definition 1(i) by day of the week between 2007 and 2014.

graph looks like a transition from control to chaos in pricing. However, our forensic analysis in Section 4 unveils a systematic equilibrium transition underlying Figure 3.

Price cycle length experiences a concurrent evolution. We illustrate this in Figure 4 by plotting market cycle length over our sample period.[18] This figure complements Figure 3 in revealing three distinct phases. First, there are 7-day cycles between January 2007 and March 2010, reflecting the Thursday and Friday focal restoration days. Second, there is a curious transition in cycle length between March 2010 and July 2011, where cycle length remains stable but mainly varies between 7 and 8 days. The start of this phase corresponds precisely to when focal restoration days disappear in Figure 3. As we will see in Section 4, the persistence of 7 and 8 day cycles over this period reflects prolonged conflict among the firms over the timing of restorations week to week. Finally, starting in July 2011, cycle length grows and becomes variable, ranging from 7 to 34 days and settling between 14 and 21 days by 2013. As we further show in Section 4, this rise in cycle length and variability is concurrent with the emergence of the signal-the-consolidate pricing structure from Figure 2(b).

[18]We mark a given cycle's length in Figure 4 on the date of its corresponding market-level restoration, per Definitions 1(iii) and 1(iv).

Figure 4: BP Station-Level Restoration Rates by Day of the Week



Notes: The figure plots market-level cycle length over time, where we mark a given cycle's length on its corresponding market-level restoration date, per Definitions 1 (iii) and (iv).

4 Price-based negotiation

We now forensically investigate, at high frequency, the evolution in the retailers' behavior underlying Figures 2–4. Through this analysis, we uncover four distinct phases over seven years:

1. Testing and transitioning focal pricing rules (Jan 2007–Dec 2009).
2. Negotiating focal rules and coordination breakdown (Jan 2010–Feb 2010).
3. Recurrent cheating and focal rule unraveling (Mar 2010–Jul 2011).
4. Abandoning focal pricing for price signaling (Jul 2011–Dec 2013).

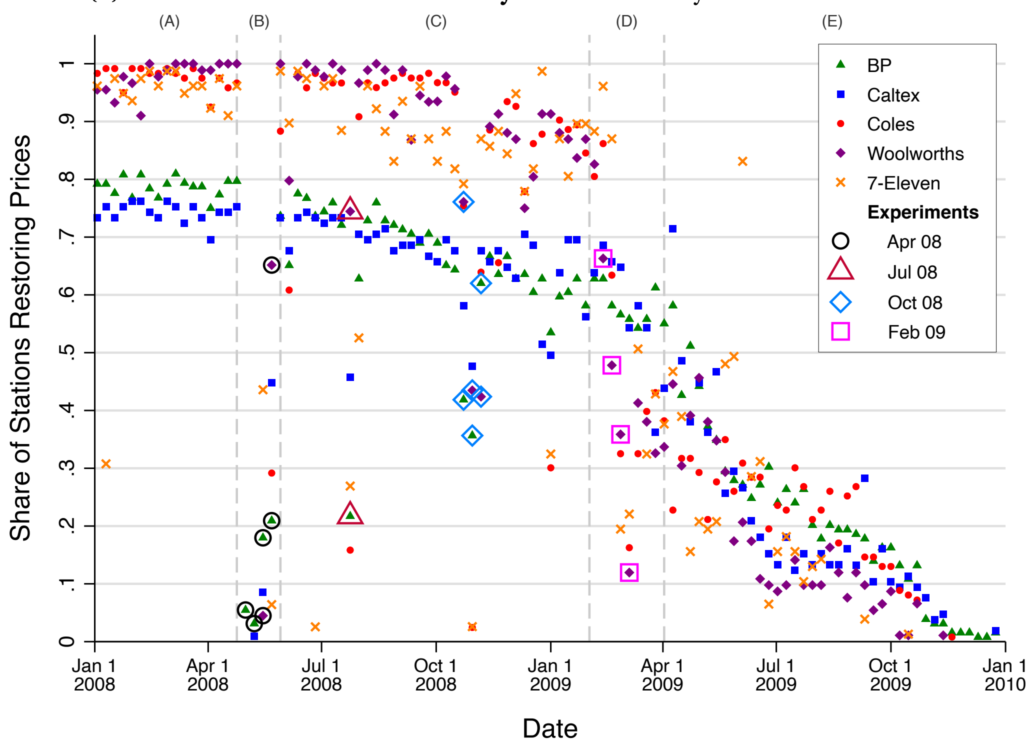
We present these phases chronologically and discuss new insights into the economics of price-based coordination that they reveal. We examine associated margin effects in Section 5.

4.1 Testing and transitioning focal pricing rules

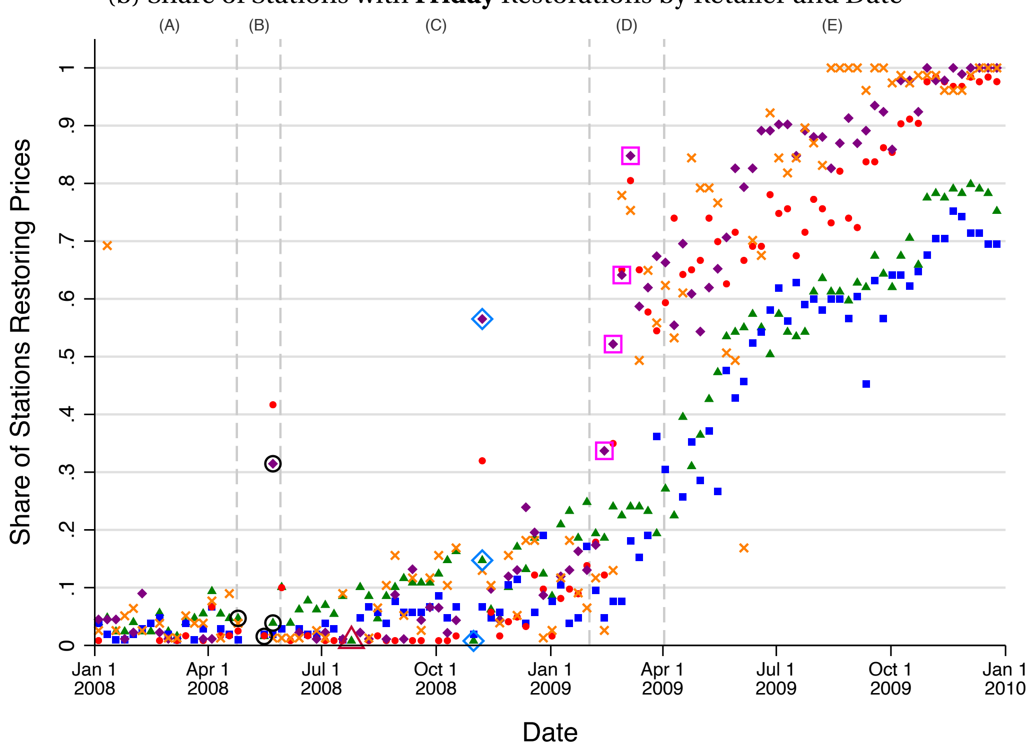
Recall from Figure 3 that Thursday restorations are a stable focal pricing rule at the sample's start but that a transition to Friday restorations eventually occurs. Panels (a) and (b) of Figure 5 zoom in on this transition and plot, by retailer and date, the share of stations engaging

Figure 5: Transition from Thursday to Friday Focal Price Restoration Days

(a) Share of Stations with **Thursday** Restorations by Retailer and Date

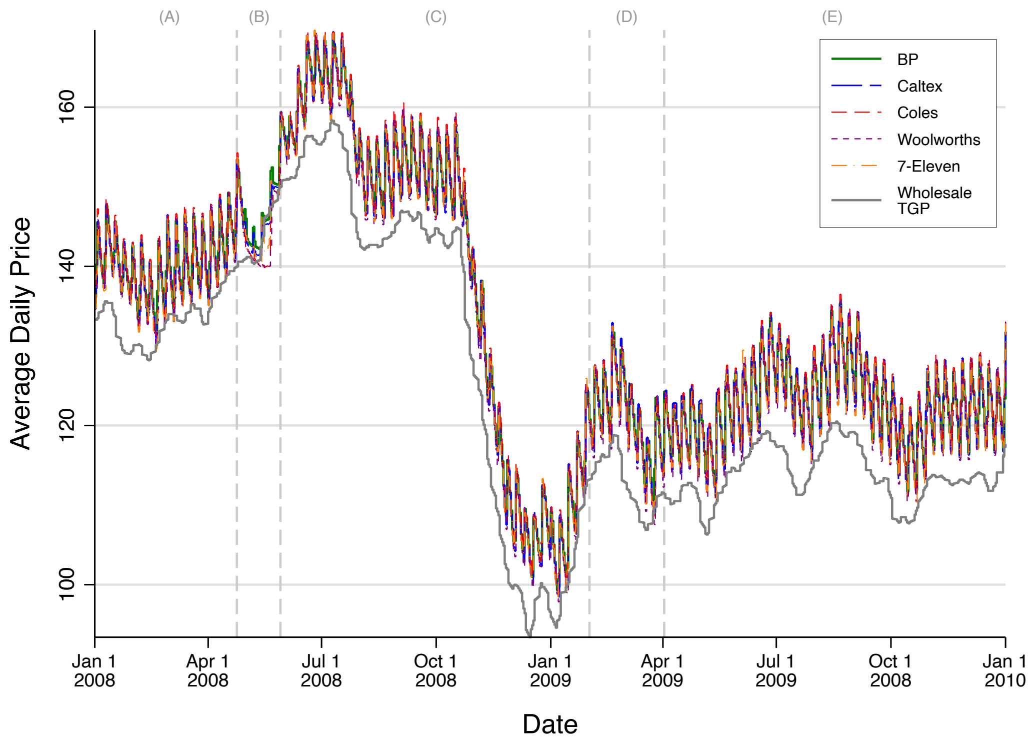


(b) Share of Stations with **Friday** Restorations by Retailer and Date



Notes: The figure plots the share of stations engaging in station-level price restorations per Definition 1(i) on Thursdays (panel (a)) and Fridays (panel (b)) by retailer between January 1, 2007 and January 1, 2010.

Figure 6: Daily Average Station-Level Prices by Retailer: January 1, 2007–January 1, 2020



in Thursday and Friday restorations between January 1, 2007, and December 31, 2009. Within this period, we uncover five micro-episodes, which we section off and label **(A)**–**(E)** at the top of the figure. Figure 6 shows how average daily prices by retailer correspondingly evolve over this period.

Per our discussion above, the retailers tightly coordinate Thursday restorations between January and April 2008 in part **(A)**. However, a gap emerges in Thursday restorations in May 2008 in part **(B)** of Figure 5(a), and the cycle correspondingly breaks down in Figure 6. During this period, BP stops restoring prices on Thursdays and experiments with Wednesday restorations (see Appendix Figure A.2). BP's rivals reveal some willingness to coordinate Wednesday restorations, except for Woolworths, which never engages in Wednesday restorations with any stations. After five weeks of coordination breakdown in part **(B)**, BP and the other retailers re-establish Thursday restorations, and a stable price cycle emerges in Figure 6. Notably, however, at the end of part **(B)** in Figure 5(b), there is a week where Woolworths and Coles experiment with delayed Friday restorations. This foreshadows future behavioral change.

After this disruptive period, part **(C)** of Figure 5 reveals a gradual transition by BP and Caltex from Thursday to Friday focal restoration days between May 2008 and January 2009. Along the transition, two experimentation episodes occur starting in July (one week) and October 2008 (five weeks), respectively. In these episodes, BP again sharply reduces its leadership of Thursday restorations, though not to the extent of its April 2008 experiment. Unlike BP's previous experiment in part **(B)**, the price cycle in Figure 6 remains stable throughout the gradual transition to Friday restorations and tempered pricing experiments in part **(C)**. Lastly, we again find Woolworths and Coles experiment with a delayed Friday restoration at the end of the October 2008 experiments.

Explicit cheating without punishment. Such repeated experimentation with price leadership and restoration timing reflects similar behavior by these retailers in other markets around this period (Byrne and de Roos, 2019). Importantly, the experiments and focal rule transition in parts **(B)** and **(C)** would shed light on the costs and benefits of leading and following restorations and the robustness of the cycle to the intensity of price leadership. Here and throughout, we emphasize two key aspects of strategic delay with restorations, as, for example, BP and Caltex engage in relative to Coles and Woolworths at the start of part **(C)**. First, any delay in restoring prices relative to rivals entails substantial price undercutting with potentially significant gains in market share. Such gains derive from the fact that restorations involve large 20% price increases and gasoline cross-price elasticities are substantial.[19] Second, as subscribers to the Informed Sources platform, the major retailers can quickly observe any delays to restoration because they share high-frequency information on station-level prices. In other words, delaying restorations does not entail "secret price-cutting" as in, e.g., Stigler (1964) or Green and Porter (1984).

Given large and explicit business stealing effects from BP's and Caltex's gradual delay in restoring prices in the first half of part **(C)** in Figure 5, it is perhaps surprising that Coles and Woolworths do not immediately retaliate by price cutting as well (i.e., akin to Grim Trigger or Tit-for-Tat punishment). Part **(C)** in Figures 5 and 6 thus provide initial evidence of explicit cheating without immediate punishment while maintaining coordination.[20] The price experiments across parts **(A)**–**(C)** reveal that *some* price leadership is needed for successful cycle coordination. However, coordination is possible with less intensive and costly restoration price leadership by BP and Caltex, with rivals initially appearing willing to accommodate the shift in leadership intensity.

[19]Estimates of the cross-price elasticity of demand in retail gasoline markets range from −20 to −40 (Houde, 2012; Clark and Houde, 2013; Wu et al., 2024; Byrne et al., 2024b). We return margin effects in Section 5 below.

[20]Genesove and Mullin (2001) similarly find evidence of cheating without punishment with the U.S. Sugar Institute. There is, however, a distinct difference in the nature of cheating with the Sugar Institute. The Institute's members "held court" to resolve informational asymmetries and determine whether cheating on a collusive arrangement (which involved multiple parts) was an accident or intentional. Because of the Informed Sources platform, our context has a simplified, process with just price setting and no private information blurring cheating detection.

The experiments and transition in parts **(A)**–**(C)** are revealing in one additional important way. They illustrate the willingness of BP to consider other days of the week when implementing the focal restoration rule in coordinating the cycle. The departure from Thursday restorations in January 2007 is precedent-setting as Thursday restorations date to at least June 2006 (i.e., the earliest date we have Informed Sources pricing data on). In this way, BP puts the possibility of alternative restoration days "on the table."

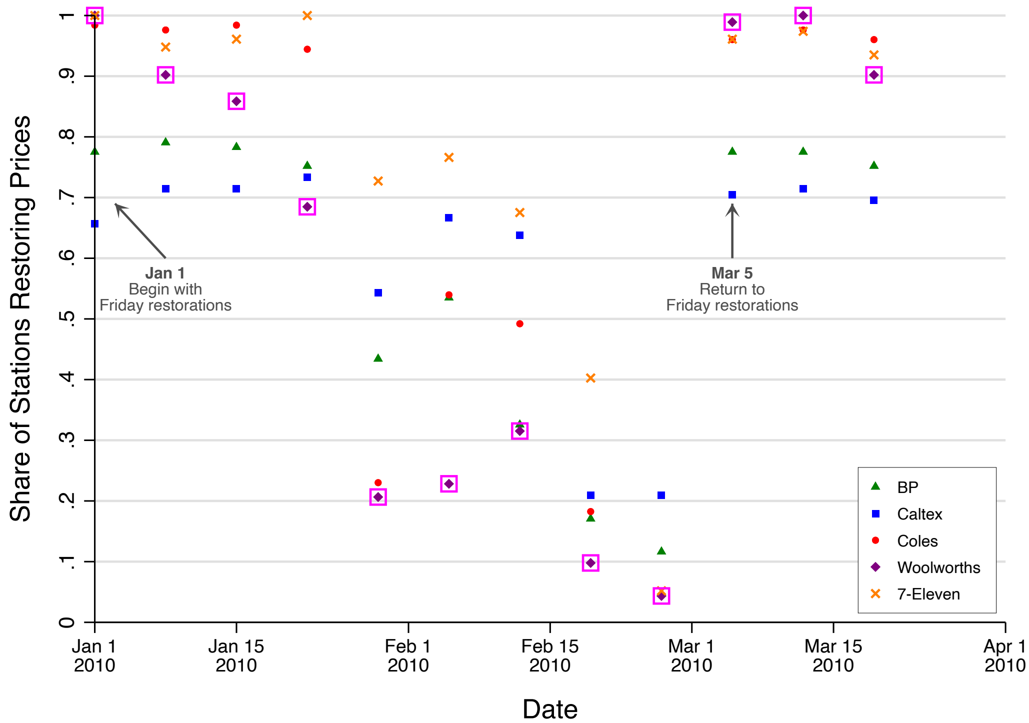
Retaliation and transition acceleration. Period **(D)** in Figure 5, which spans February and March 2009, exhibits a remarkable shift in behavior by Woolworths. Starting in February 2009, Woolworths drastically shifts from 85% of its stations restoring prices on Thursdays to 85% restoring on Fridays. Within the first three weeks of Woolworths' shift to Friday restorations, Coles, its main rival in grocery retailing, moves to match Woolworths' restoration timing. This drastic experimental delay in restorations eventually settles with Woolworths and Coles' restorations, rebounding to approximately 40% Thursday restorations and 60% Friday by the end of part **(D)**. BP and Caltex persist with Thursday restoration intensity throughout part **(D)** with nearly 60% of their stations restoring prices then. In effect, part **(D)** contains a reversal in price undercutting, with Woolworths and Coles now stealing business from BP and Caltex.

Given the history in parts **(A)**–**(C)**, the break in Woolworths' behavior in part **(D)** can be seen as retaliatory cheating. With BP and Caltex's gradual transition to Friday restorations in part **(C)**, Woolworths may anticipate an ongoing transition to a new focal pricing rule, choosing to steal business from BP and Caltex by accelerating the transition. In doing so, Woolworths also faces strategic uncertainty and potential punishment from its rivals; however, there is also collective awareness and precedent of cheating without punishment from the transition's part **(C)**. Part **(E)** shows that no punishments come, and BP and Caltex eventually accommodate Woolworths and Coles and fully transition to Friday restorations by the end of 2010.

Ultimately, the retailers end up at the end of Figure 5(b) exactly where they start in Figure 5(a), just with Friday being the focal restoration day. Except for an experimental absence of price leadership by BP in part **(B)**, cycle coordination in Figure 6 remains stable throughout this period of experimentation, cheating, and equilibrium transition. That explicit cheating can persist for more than a year without coordination breakdown reflects a key tension. Absent explicit communication, the retailers are unable to establish clear "rules of engagement" to support coordination. Limited communication creates such strategic uncertainty (Brandenburger, 1996), restricting firms' ability to implement fast-targeted punishment toward cheaters. Thus, there is scope for testing and learning these rules and their boundaries through experimentation with price leadership, strategic delay, and undercutting.

Figure 7: Negotiating Focal Restoration Days

(a) Share of Stations with **Friday** Restorations by Retailer and Date



(b) Share of Stations with **Saturday** Restorations by Retailer and Date

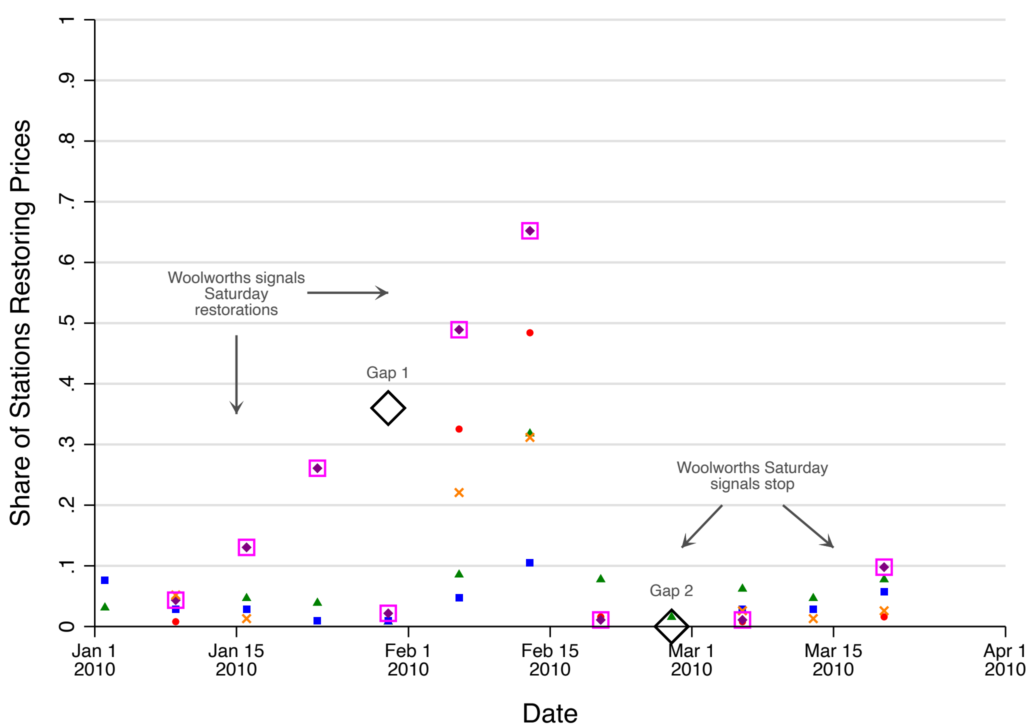
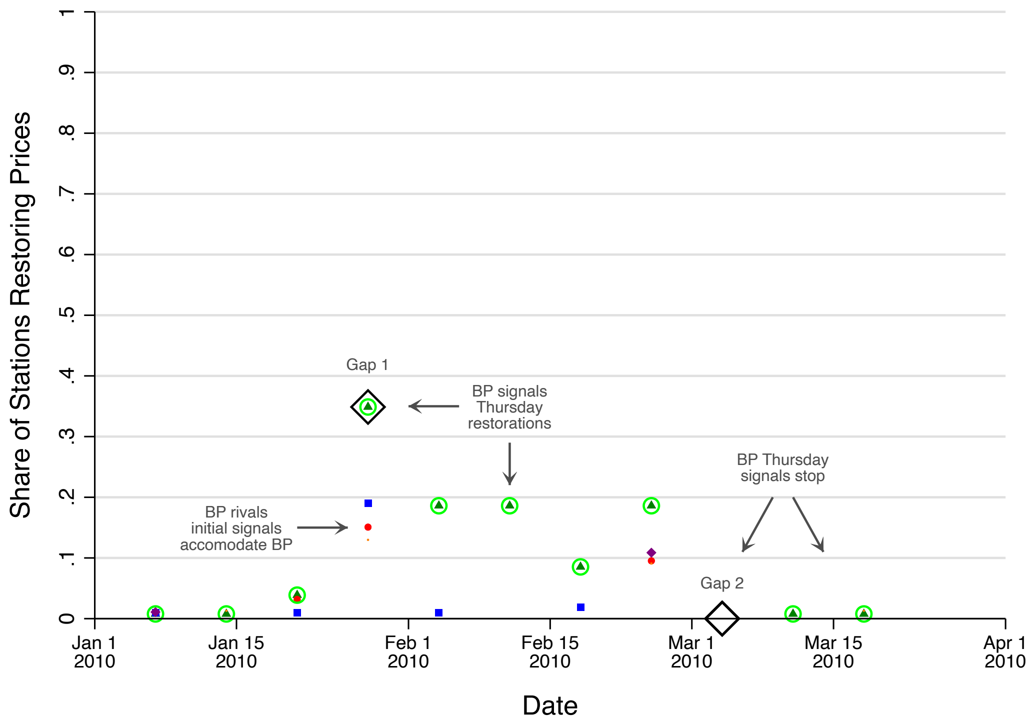


Figure 7: Negotiating Focal Restoration Days (continued)

(c) Share of Stations with **Thursday** Restorations by Retailer and Date



Notes: The figure plots the share of Caltex, Coles, Woolworths, and 7-Eleven stations engaging in station-level price restorations per Definition 1(i) on Fridays (panel (a)), Saturdays (panel (b)), and Thursdays (panel (c)) between January 1, 2010 and March 21, 2010.

4.2 Negotiating focal rules and coordination breakdown

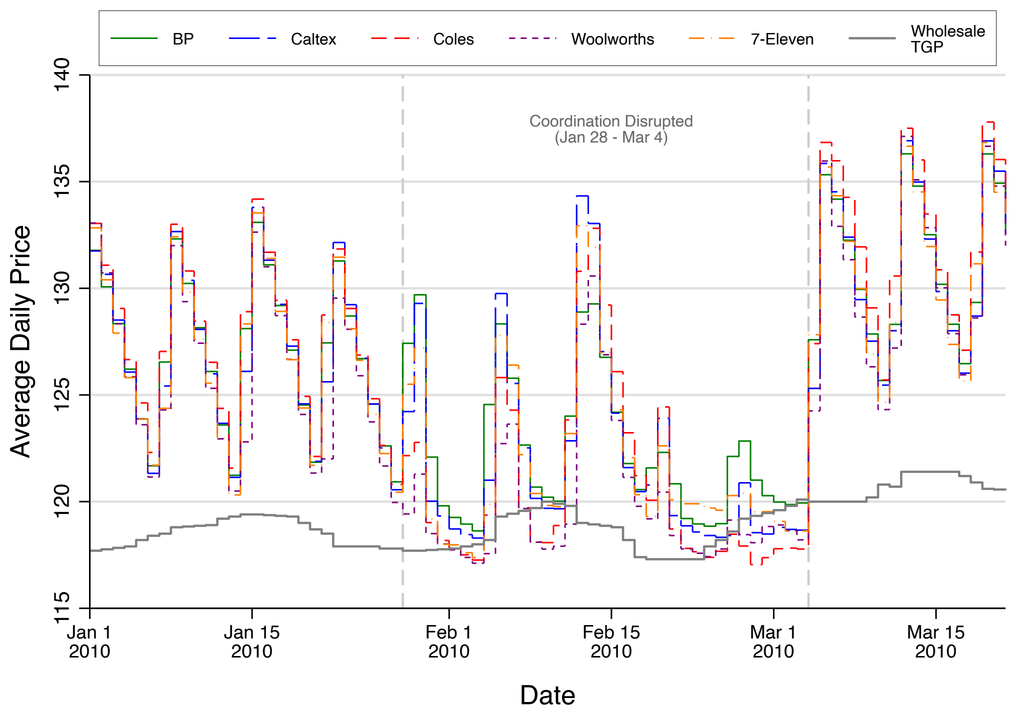
The retailers enter a three-month negotiation process over the focal restoration day between January and March 2010. Panels (a)–(c) of Figure 7 present the process, respectively plotting retailers' shares of stations engaging in Friday, Saturday, and Thursday restorations over the period.[21] Figure 8 illustrates an accompanying collapse in cycle coordination during this period of negotiation and conflict.

Beginning with Figure 7(a), the retailers tightly coordinate Friday restorations at the beginning of 2010. However, after the year's first restoration, Woolworths again starts defecting on the focal pricing rule. This time, Woolworths abruptly shifts from Friday to *Saturday* price restorations. Indeed, panels (a) and (b) show that in just six cycles, Woolworths shifts from 100% Friday restorations to 67% Saturday restorations by February 15.

The other retailers' reactions to Woolworths' defection differ in two substantive ways from their 2009 responses. First, panel (a) reveals that the rivals respond within just one month: by

[21] For the exposition, presenting these three days of the week in this order is clearest.

Figure 8: Daily Average Station-Level Prices by Retailer: January 1, 2010–March 21, 2010



the fourth week of Woolworths' defection, all other retailers transition away from Friday restorations. These findings illustrate how other retailers, especially BP and Caltex, actively limit their exposure to and reduce Woolworths' gains from cheating on focal restoration timing.

Second, in panels (b) and (c), we find evidence of counter-proposals by BP in response to Woolworth's defection to Saturdays. We highlight these events with "Gap 1" in the two panels. In panel (b), we find a gap in the linear upward trend in Woolworths' transition to Saturday restorations. Panel (c) plots *Thursday* restoration rates and shows BP restores 35% of its stations' prices on Thursday in Gap 1. The day of the week is important for interpreting Gap 1 in panels (b) and (c). In panel (c), Caltex, Coles, and 7-Eleven signal an initial willingness to restore prices on Thursday with BP in Gap 1. Two days later, Woolworths reverses course in panels (a) and (b) and temporarily pauses the transition to Saturday restorations for one week in Gap 1 in panel (b). Indeed, Woolworths barely restores prices at any stations in Gap 1 across panels (a)-(c). Miscoordination and a lack of restorations in the week of Gap 1 causes a coordination breakdown and a failed restoration. Notably, in reacting to BP's signal of Thursday restorations in Gap 1, Caltex, Coles, and 7-Eleven would *not* have known Woolworths' response. By Sunday in the week of Gap 1, they would have: Woolworths is uninterested in returning to Thursday restorations from 2009.

The week following Gap 1 in panels (b) and (c) (i.e., the two cycles between February 1 and 15), Caltex, Coles, and 7-Eleven are left with a choice: coordinate restorations with BP on Thursday or Woolworths on Saturday. Figures 7(b) and (c) show they abandon BP in favor of Woolworths in coordinating Saturday restorations. However, Caltex's response is initially weak, and BP persists in signaling Thursday restorations throughout February. Effectively, between February 15 and March 4, the retailers are at a crossroads over the focal rule, and this comes to a head in Gap 2 in Figures 7(b) and (c). In this week, BP, Woolworths, and the other retailers abandon restorations altogether. Figure 8 shows this again causes coordination breakdown and price cycle collapse between February 15 and March 4, leaving all retailers' prices near wholesale cost.

Negotiations finish at a standstill, and the retailers tightly coordinate a Friday restoration on March 5 in Figure 7(a). Prices immediately jump from marginal cost, and a stable price cycle reemerges in Figure 8. In sum, after two months of negotiation and coordination breakdown, the retailers end up exactly where they started in January 2010.

Renegotiation with price-based communication. A substantial literature in collusion research emphasizes the central role of price wars and renegotiation in collusion.[22] Whereas price wars and renegotiation under explicit collusion arise from frictions such as incomplete monitoring and private information (Green and Porter, 1984), in our setting with perfect monitoring, a price war and renegotiation process emerges because of strategic uncertainty over punishment strategies. Our key insight for collusion research and antitrust policy is that price-based renegotiation is possible with platform-enabled price information sharing. Such platforms can yield a sufficiently rich communication medium to facilitate renegotiation over a collusive pricing structure.[23] This starkly contrasts with previous literature, where explicit communication (i.e., human language) is the implicitly assumed communication channel among cartel members. We return to the implications of our novel finding of price-based negotiation for future collusion research and antitrust policy in Section 6.

4.3 Recurrent cheating and focal rule unraveling

Negotiations over the focal restoration day soon continue after the March 2010 standstill. Figure 9 illustrates this through another zoomed-in plot of retailers' shares of station-level restora-

[22] See, e.g., Levenstein and Suslow (2006b) or Marshall and Marx (2012) for an extensive review of cartels, price wars, and renegotiation.

[23] This result complements a large empirical literature on price leadership, signaling, and collusion, establishing various ways firms can use market prices, possibly enabled by platforms, to implement pricing structures that create supra-competitive margins.(e.g., Cramton and Schwartz, 2002; Borenstein, 2004; Lewis, 2012; Byrne and de Roos, 2019; Luco, 2019) Our evidence pushes this area of research further to show how firms can use market prices to *negotiate over and transition between* such pricing structures.

tions on Fridays (panel (a)) and Saturdays (panel (b)) between March 1 and May 2010. After well-coordinated Friday restorations in the first three weeks of March, in the fourth week, Woolworths again abruptly drops its Friday restoration shares to 35% and raises its Saturday shares to 65%. All rivals quickly follow in switching from Friday to Saturday restorations in the fourth week in panels (a) and (b).

The fifth week, which we label "Gap 3" yields another disruption in Woolworths' attempted transition. As shown in Appendix Figure A.3, BP again counter signals with Thursday restorations in Gap 3 with Caltex signaling a willingness to coordinate. Figure 9(a) shows that this causes Woolworths to shift back to Friday restorations the following day immediately. These signals and proposals over Thursday versus Saturday restoration days further underline a bargaining process over the structure of the focal pricing rule governing price cycles. The process is also persistent: by the week of Gap 3, BP and Woolworths have engaged in four months of price-based bargaining.

After Gap 3, Woolworths pushes for Saturday restorations in the latter half of Figure 9(b). In response, BP abandons Thursday restoration signals in appendix Figure A.3 and gradually transitions with Caltex to Saturday restorations. Woolworths effectively calls BP's bluff over its willingness to coordinate on Saturday restorations. Price-based bargaining evolves so the price cycle remains stable without punishments such as abandoning restorations.

Cheating cycles. At this point, it is natural to ask two questions. Why Woolworths? And why Saturdays? Before delving into these questions, it is helpful to document another novel dynamic in our data. After negotiating Saturday restorations in April 2010, Woolworths starts inducing *cheating cycles* over the next 14 months until July 2011. For instance, after the retailers coordinate on Saturday in April 2010, Woolworths abruptly defects and starts engaging in *Sunday* restorations. Then, once all the retailers coordinate on Sunday restorations, Woolworths abruptly defects again with *Monday* restorations, and so on.

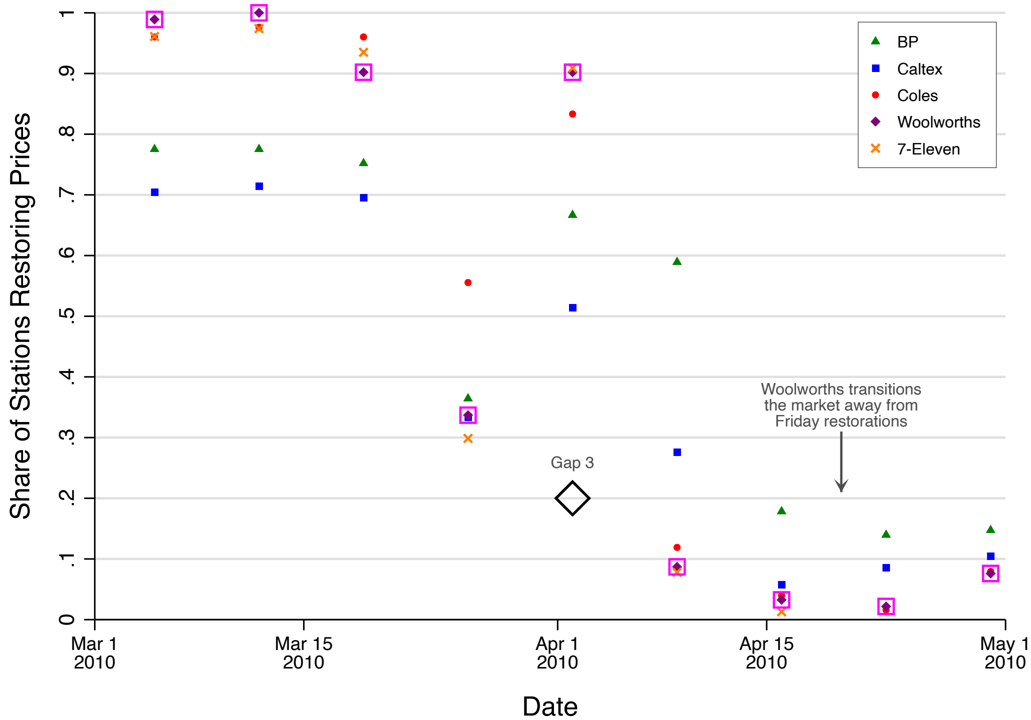
We illustrate this extraordinary dynamic in panels (a)–(d) of Figure 10. Respectively, these panels plot the retailers' shares of stations engaging in Friday, Saturday, Sunday, and Monday restorations between January 1, 2010, and July 2011.[24] Moving from panel (a) to (d), we add a focal restoration day in bold color and gradually shade out previous restoration days of the week from the previous panels. Along the top of the graphs, we label the restoration days of the week over time, emphasizing transitions between them over the period with arrows. Exploiting our high-frequency data, we confirm that Woolworths leads in these cheating cycles, similar to their behavior from Figure 9.[25] Within the broader context of Figure 10, Figures 7 and 9 represent the

[24]For brevity, we report graphs including Tuesday, Wednesday, and Thursday restorations in the Appendix. These confirm the Woolworths-led cheating cycles in Figure 10.

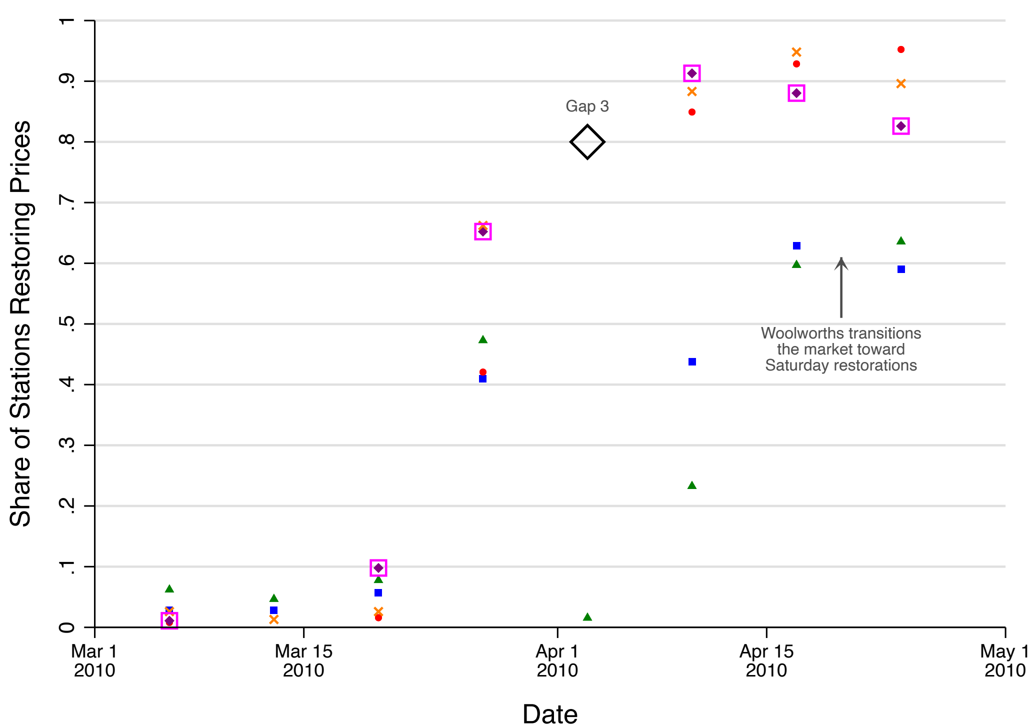
[25]Notice that cheating cycles in Figure 10 are separate from price cycles; they are cycles in the restoration day

Figure 9: Recurrent Cheating on Focal Restoration Days

(a) Share of Stations with **Friday** Restorations by Retailer and Date



(b) Share of Stations with **Saturday** Restorations by Retailer and Date



Notes: The figure plots the share of BP, Caltex, Coles, Woolworths, and 7-Eleven stations engaging in station-level price restorations per Definition 1(i) on Fridays (panel (a)) and Saturdays (panel (b)) between March 1, 2010 and May 1, 2010.

first two (attempted) cheating cycles by Woolworths at the start of 2010.

Figure 10 has two other noteworthy features. First, panel (d) highlights four cheating cycles that gradually shorten over time. For instance, cheating cycle #1 spans 24 weeks (April to September), transitioning from Friday restoration days. In contrast, cheating cycle #4 spans just 6 weeks over an analogous transition. Figure 11 provides a complementary visualization of the evolution of cheating cycles by plotting the market-level restoration day of the week over time.[26] Within Phase 3 in the graph, the four cheating cycles illustrate how the restoration day cycles through the week from Mondays to Sundays, with the cycles shortening over time.[27] As we will see in Section 5, the increase in cheating cycle speed implies that Woolworths gains less from cheating through restoration delay over time. In effect, Woolworths' rivals gradually learn of and adapt to Woolworths' repeated cheating such that by the end of July 2011, they match Woolworths in shifting the restoration day by one day week-to-week.

The second key result in Figure 10 is that the overall level of restoration activity remains largely constant. For example, recurrent and predictable cheating by Woolworths between March 2010 and July 2011 is never met with punishments such as temporarily abandoning restorations and pricing closer to wholesale cost. Indeed, despite the constant state of flux in restoration timing in Figure 10 and substantial revenue losses for Woolworths' rivals (detailed in Section 5), price cycles remain stable throughout the period in Figure 12. Recalling Woolworths' first cheating episode from Figure 7 occurs in February 2009, our findings here reveal a two-and-half-year period of explicit cheating by Woolworths without punishment or coordination breakdown, except for the two-month negotiation period in early 2010, which ended in a stalemate.

Price-based negotiation among asymmetric retailers. We now return to the question of why Woolworths? One key factor from Section 2 is that Woolworths (and Coles) are dominant grocery retailers that tie gasoline price discounts to grocery purchases. In contrast, BP and Caltex do not operate national retail grocery chains. Thus, there are *asymmetric retailers* in the gasoline market as Woolworths and Coles disproportionately benefit from undercutting rivals' gasoline prices to increase retail market shares at their stations and grocery stores. Clark and Houde (2013) emphasize a similar tension between grocery and non-grocery gasoline retailers engag-

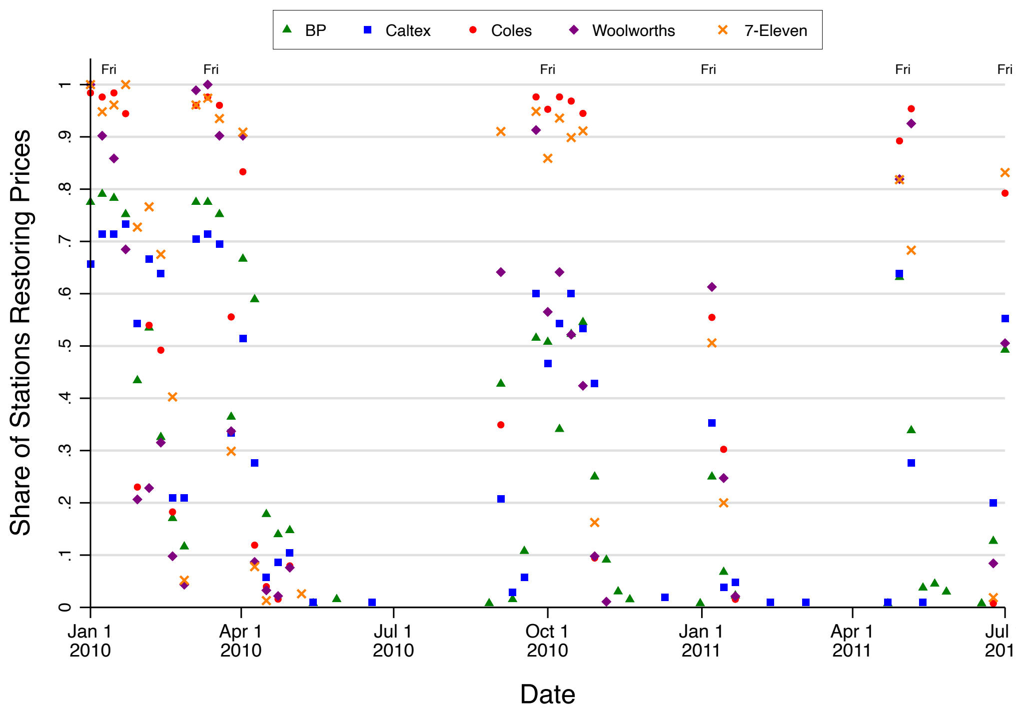
of the week over time induced by Woolworths persistently delaying price restorations by one day of the week (i.e., on day of week $d+1$) after its rivals begin coordinating restorations on a particular day of the week (i.e., on day of week d).

[26]A given data point in the Figure contains the date and day of the week a given market-level restoration occurs on, where recall we classify market-level restorations per Definition 1.

[27]The cheating cycles in Figure 11, which repeatedly induce one-day shifts in the focal restoration day across consecutive weeks, is precisely what generates the '7 or 8-day cycles' phase in the market cycle length between March 2010 and July 2011 in Figure 4 above.

Figure 10: Focal Restoration Day Cheating Cycles

(a) Share of Stations with **Friday** Restorations by Retailer and Date



(b) Share of Stations with **Saturday** Restorations by Retailer and Date

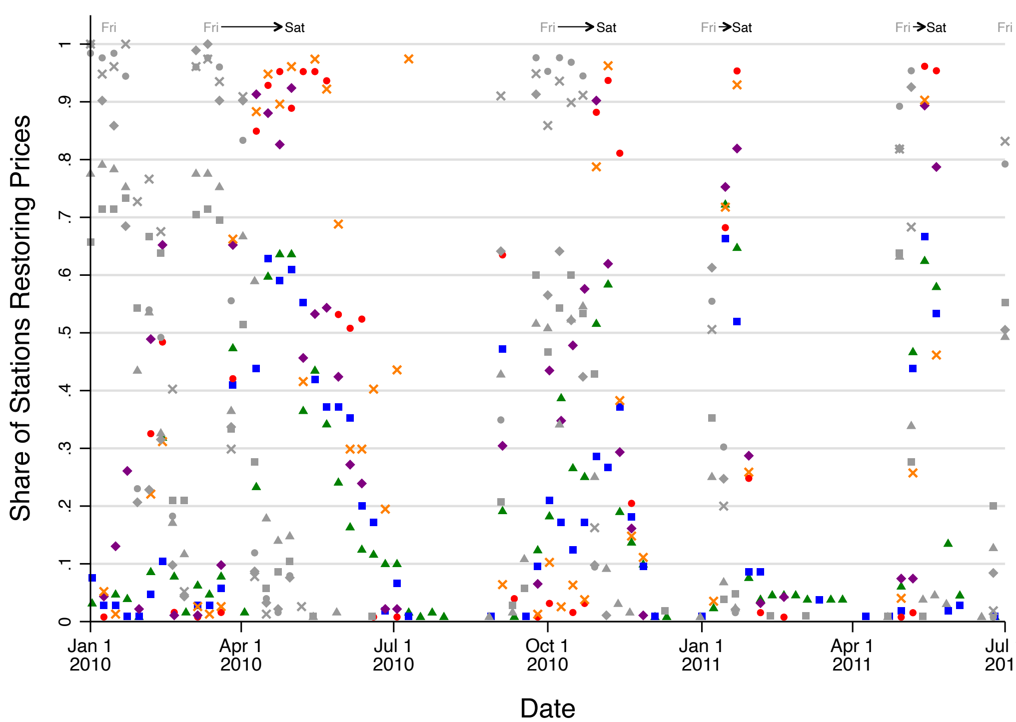
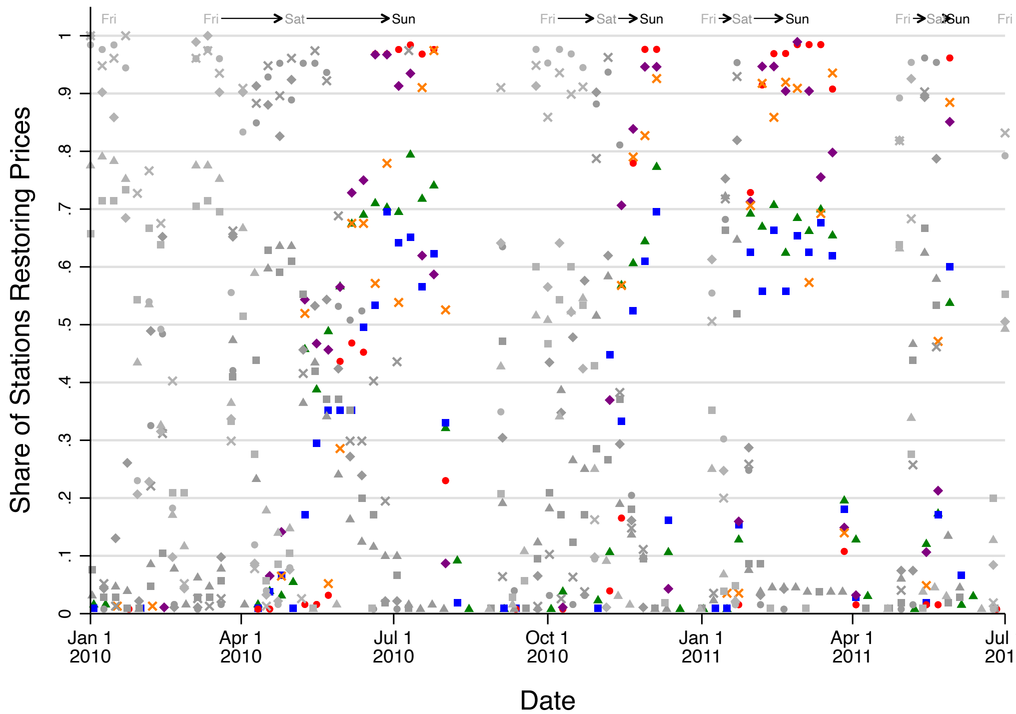
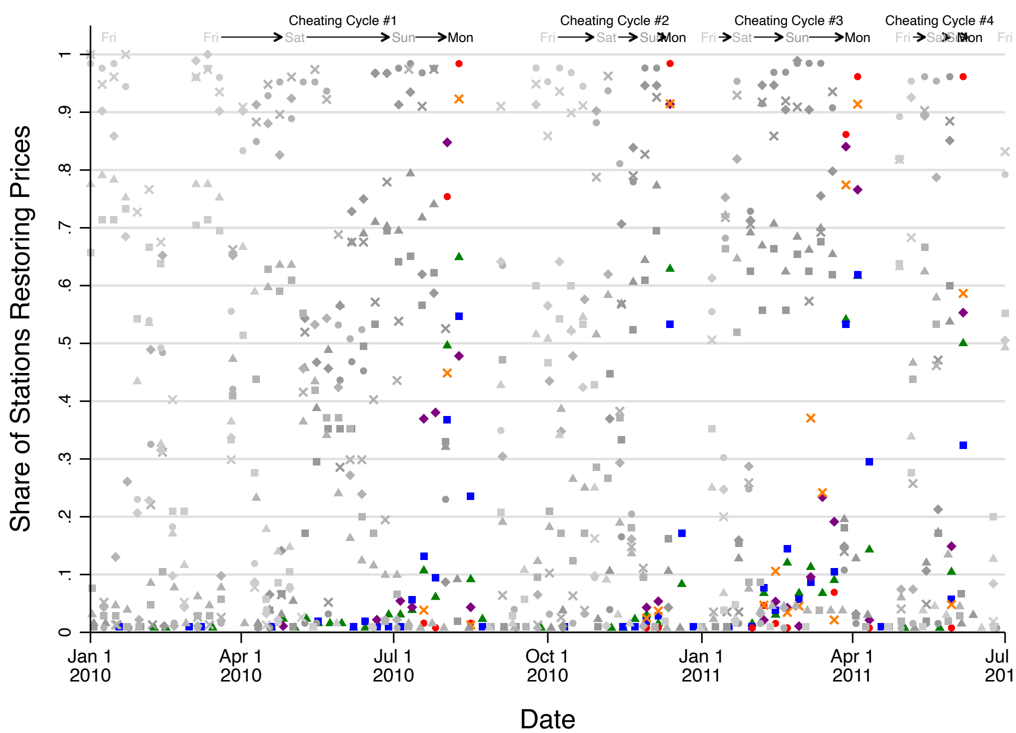


Figure 10: Focal Restoration Day Cheating Cycle (continued)

(c) Share of Stations with **Sunday** Restorations by Retailer and Date

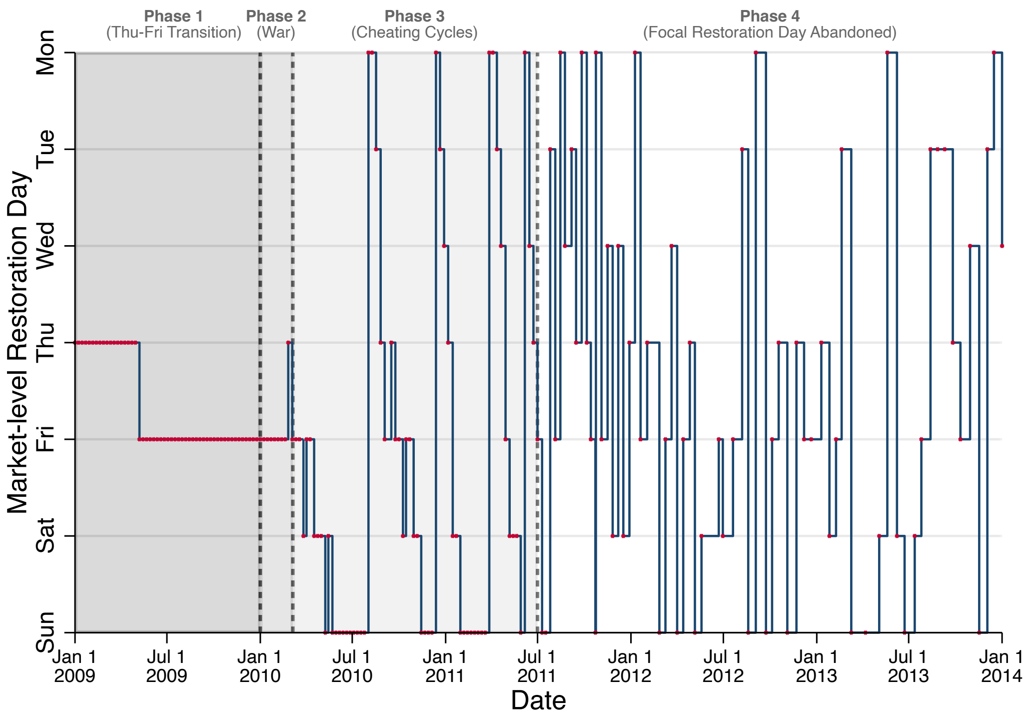


(d) Share of Stations with **Monday** Restorations by Retailer and Date



Notes: The figure plots the share of BP, Caltex, Coles, Woolworths, and 7-Eleven stations engaging in station-level price restorations per Definition 1(i) on Fridays (panel (a)), Saturdays (panel (b)), Sundays (panel (c)), and Mondays (panel (d)) between January 1, 2010 and July 1, 2011.

Figure 11: Market-Level Restoration Days of the Week



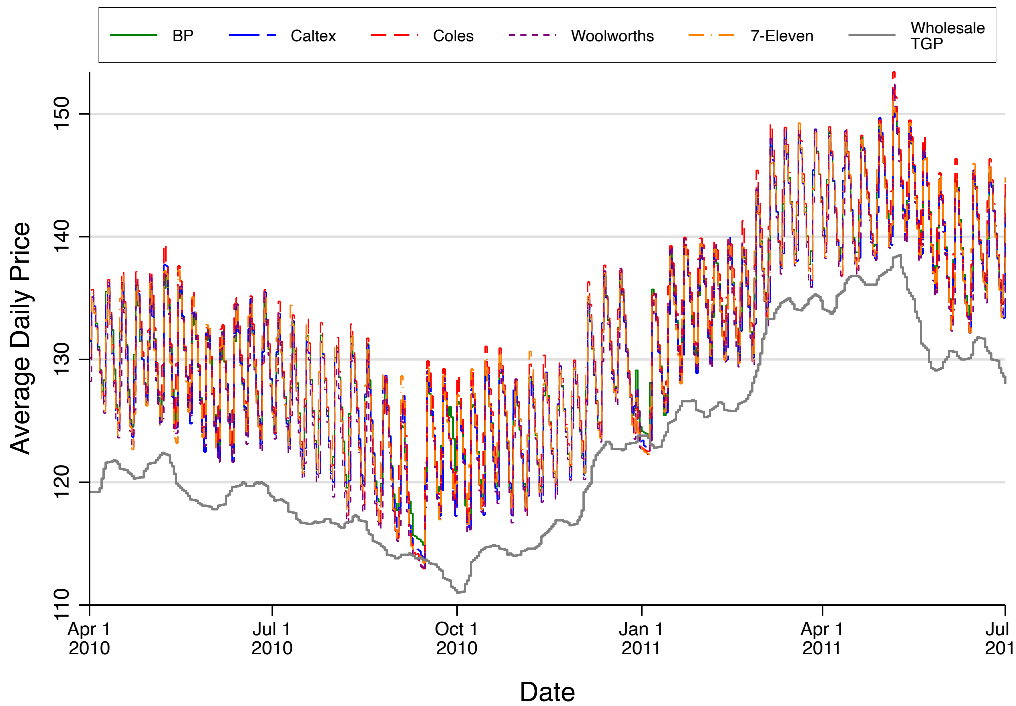
Notes: The figure plots the day of the week that a market-level restoration occurs between January 1, 2009 and January 1, 2014, per Definitions 1 (iii). Each circle marker in the figure corresponds to a market-level restoration event. The differentially shaded areas correspond to the four phases of firms' underlying pricing structures that we examine in this section.

ing in *explicit collusion*. Grocery-connected gasoline retailers are "efficient types" in negotiating collusive pricing structures who can credibly commit to undercutting and disrupting a gasoline pricing structure to enhance grocery store profits if the structure does not account for grocery-related profits. Such asymmetry in incentives can explain Woolworths' explicit cheating in our setting.[28]

Woolworths' persistence in cheating over two years reflects a lack of communication among retailers over rules that govern price coordination, testing, and learning the boundaries of cooperation among the retailers. Woolworths correctly anticipates its rivals' lacking will to punish its cheating by, e.g., abandoning restorations. Through such cheating, Woolworths is visibly the lowest-priced major retailer to consumers throughout 2010–2011, attracting new customers and generating in-store benefits through tied grocery purchases. Recall, however, from Figures

[28]A related question is why Coles would not drive recurrent cheating. One possibility is that Coles tends to have uniformly-timed restorations across its entire station network. In contrast, Woolworths is comparatively flexible with restorations and times restorations differentially across different stations week-to-week. Such flexibility among Woolworths' stations in restoration timing allows it to more nimbly respond to counter-signals from other rivals regarding restoration timing, such as when BP signals Thursday restorations in early 2010.

Figure 12: Daily Average Station-Level Prices by Retailer: April 1, 2010–July 1, 2011



10 and 11, that we find a gradual adaptation by the rivals that would "stem the bleeding" (in terms of lost gasoline sales) from Woolworths' recurrent cheating by matching their restoration timing by the end of 2011. It turns out that this evolution precipitates a further evolution in the overarching pricing structure.

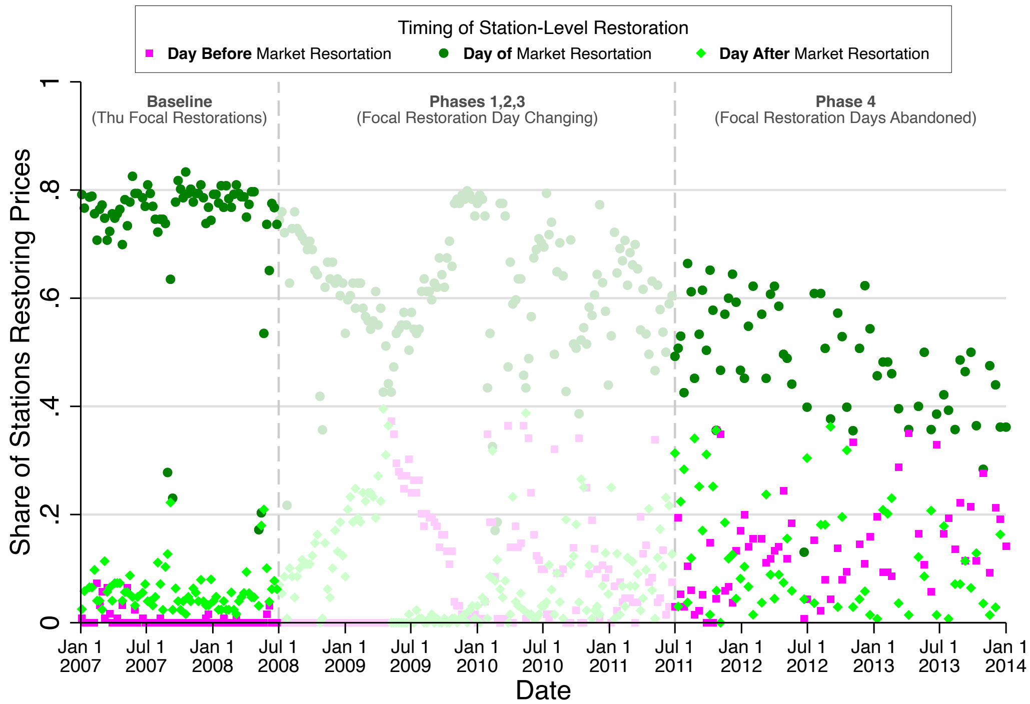
4.4 Abandoning focal pricing for price signaling

In the final phase of the equilibrium transition, from July 2011 to January 2014, the retailers abandon focal restoration days for coordination altogether. The pricing structure evolves to using price signaling instead of focal rules to coordinate restorations. Our motivating figures in Section 3 foreshadow this long-run change in the pricing structure. Figure 2(a) illustrates tightly coordinated weekly one-day focal restorations on Thursdays in 2007, while Figure 2(b) reveals a multi-day restoration phase in 2013 with a two-part signal-then-consolidate structure.

Figure 13 illustrates the transition to a signal-then-consolidate pricing structure after July 2011. Here, we contrast the baseline phase with focal restoration days (Jan 2007 - Jul 2008) and the final phase with price signaling (Jul 2011 - Jan 2014).[29] We construct the figure in two

[29]To emphasize long-run differences in the pricing structure, we shade out the transitory Jul 2008–Jul 2011 period where focal restoration days are repeatedly changing, mainly due to recurrent cheating by Woolworths.

Figure 13: Timing of BP Station-Level Restorations Around Market-Level Restorations



Notes: The figure plots the share of BP stations engaging in station-level restorations the day before, day of, and day after market-level restorations between January 1, 2009, and January 1, 2014, per Definitions 1.

steps. First, we identify market-level restorations per Definition 1. Second, for each market-level restoration, we compute, by retailer, the share of stations engaging in station-level restorations the *day before*, the *day of*, and the *day after* a market-level restoration. Figure 13 plots these station restoration shares for BP for the day before, days of, and day after market restoration events.[30] After July 2011, there is a transition to diversified restoration phases whereby BP restores prices at a subset (≈ 20%) of stations the day before a market-level restoration. Then, ≈ 50% of BP stations coordinate restorations on the market restoration day, and a final ≈ 10% of stations restore prices the day after the market restoration. This three-day approach to implementing restorations starkly contrasts the baseline focal restorations from 2007-08, where BP repeatedly restores its stations' prices simultaneously on Thursdays each week.

We formally test for the change in equilibrium pricing structure at the start (Jan 1, 2007 – Jul 1, 2008) and end of our sample (Jul 1, 2011 – Jan 1, 2014) using the following linear probability model:

$$\text{Rest}_{it} = \alpha_0 + \sum_{j=-3}^{3} \left[\beta_j \times \text{MktRest}_{jt} + \gamma_j \times \text{Signaling}_t \times \text{MktRest}_{jt}\right] + \epsilon_{ijt}, \tag{1}$$

[30]In the Appendix, we provide analogous plots for the other retailers in Figure A.4. They illustrate similar long-run transitions from focal pricing to price signaling.

where Rest_{it} equals 1 if station i restores its price on date t and 0 otherwise, MktRest_{jt} equals 1 if date t is j days away from a market restoration and 0 otherwise, and Signaling_t equals 1 if t is after July 2011, or when the firms use price signaling in place of focal restoration days of the week to coordinate price increases. Given a set of market restoration dates, we construct the MktRest_{jt} dummy variables in (1) based on dates that fall within a 7-day window of a market restoration date, including the market restoration date itself. We cluster ϵ_{ijt} by station and date to account for persistence in restoration behavior across stations on a given date and within a given station over time.

Interpreting the coefficients in (1), β_j quantifies a station's propensity to restore its prices within $j = -3, \ldots, 3$ days of a market restoration under *focal pricing* at the start of our sample.[31] For $j < 0$, the coefficients measure the propensity for stations to *lead* market restorations. For $j = 0$ and $j > 0$, the coefficients respectively measure the propensity for stations to *go with* and *follow* market restorations. The sum $\beta_j + \gamma_j$ quantifies a station's propensity to lead $(j < 0)$, go with $(j = 0)$, or follow $(j > 0)$ market restorations under *price signaling* at the end of our sample. We estimate separate β_j and γ_j coefficients for each major retailer, reflecting the equilibrium nature of the timing game with restorations.

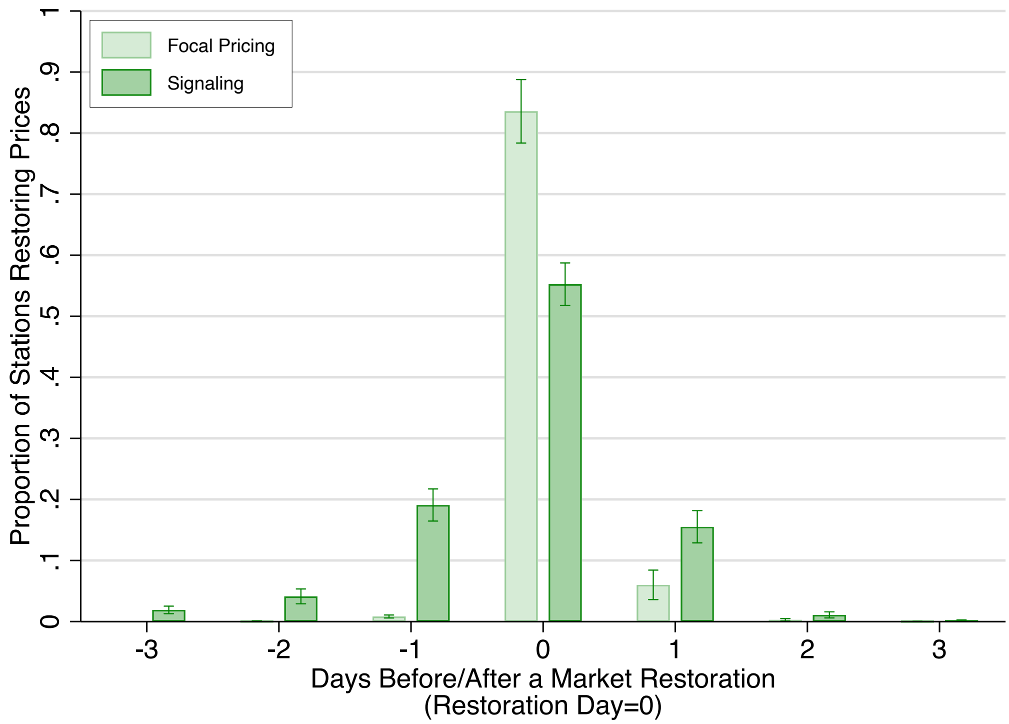
Figure 14 presents our coefficient estimates for BP.[32] Our results highlight a clear shift from focal restoration pricing with highly coordinated restoration timing at the start of the sample to a diversified signal-then-consolidate restoration coordination mechanism at the end of the sample. Under the latter mechanism, small numbers of stations are restoring their prices two and three days ahead of a three-day restoration consolidation process. This contrasts dramatically with the large spike in restorations that are concurrent with the market restorations and rivals under focal pricing. A joint test of the that $\gamma_j = 0$ for $j = -3, \ldots, 3$ rejects the null with $p < 0.01$, confirming, statistically, a change in the restoration profile under signaling at the end of the sample.

These changes in the pricing structure after July 2011 ultimately result in longer and more volatile price cycles (Figure 4), the end of cheating cycles, and less predictable restoration days of the week (Figure 11). There are also important associated margin changes. As we will see in Section 5, the change in restoration pricing structure from focal days of the week to signal-then-consolidate raises overall margin levels and balances the allocation of profits across retailers. Viewed through the lens of a price-based negotiation process, Woolworths ultimately relents from recurrent cheating under the signal-then-consolidate structure, where both the risk of

[31] We find minimal station-level restoration activity outside of three days before and after market-level restoration in the sample.

[32] For brevity, we report analogous graphs for Caltex, Coles, Woolworths, and 7-Eleven in the Appendix. The patterns for these companies are very similar to those in Figure 14, confirming that all retailers shift from an equilibrium with focal pricing to another with price signaling.

Figure 14: BP Station-Level Restoration Timing Under Focal Pricing and Price Signaling



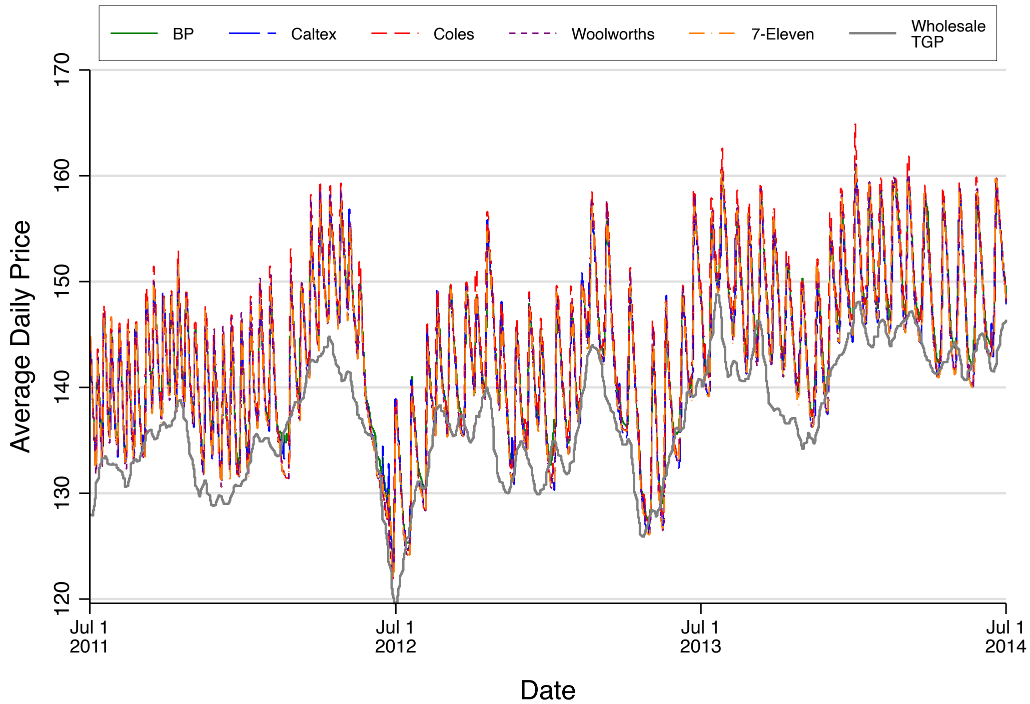
price leadership and gains to cheating from delayed restorations fall.

In addition, the signal-then-consolidate structure enables retailers to send and observe costly price signals by *all* players before coordinating a restoration.[33] Such costly signals allow retailers to reveal their willingness to participate in a market-wide restoration, propose a restoration price level, and confirm a *collective* willingness to engage in a restoration at a point in time.

Finally, Figure 15 shows that the price cycle remains stable throughout phase four despite a substantive evolution in the underlying pricing structure. In fact, after our sample period, the signal-then-consolidate pricing structure and price cycle are robust to coordination breakdown for the next six years, including through major world oil price shocks in 2014 and 2018, through to the COVID-19 pandemic (Byrne et al., 2024b).

[33] Signaling by restoring prices at a subset of stations the day before a market-wide restoration is costly because a large share of other stations in the market, including independent stations, will have much lower prices and hence ability to attract price-sensitive consumers. Such pre-restoration price signals are thus not cheap talk in the sense of Farrell and Rabin (1996). Byrne et al. (2024a) further discuss costly signaling and the role of information-sharing platforms like Informed Sources in coordinating price increases.

Figure 15: Daily Average Station-Level Prices by Retailer: July 1, 2011–Jan 1, 2014



5 How margins evolve

5.1 Cycle shape

- Figure 16(a) shows that margins at the **top** of the cycle exhibit large growth before January 2010, rising from 10 cpl to 15 cpl, then stalling or falling during cheating cycles, and remaining stable around the 15 cpl level after that.

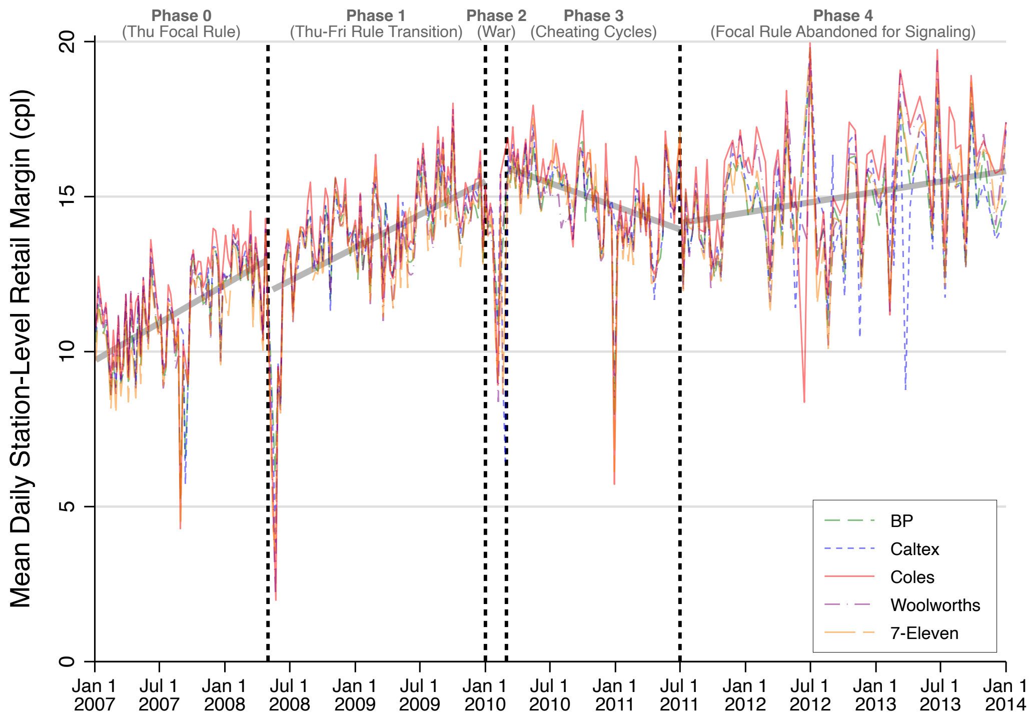
- Figure 16(b) shows that margins at the **bottom** of the cycle grow from 0 cpl in January 2007 to 2.5 cpl in July 2009, remaining stable at that level until July 2011, and then abruptly shifting to 0 cpl and remaining stable at that level after that.

- Figure 17 shows that the rate of price undercutting (between the top and bottom of the cycle) increases in magnitude/rate from approximately −1.25 to −1.75 cpl per day between January 2007 and January 1, 2010. After that, the rate of undercutting begins to slow with a shift in July 2011 such that by the end of the sample the rate of undercutting is −1 cpl per day.

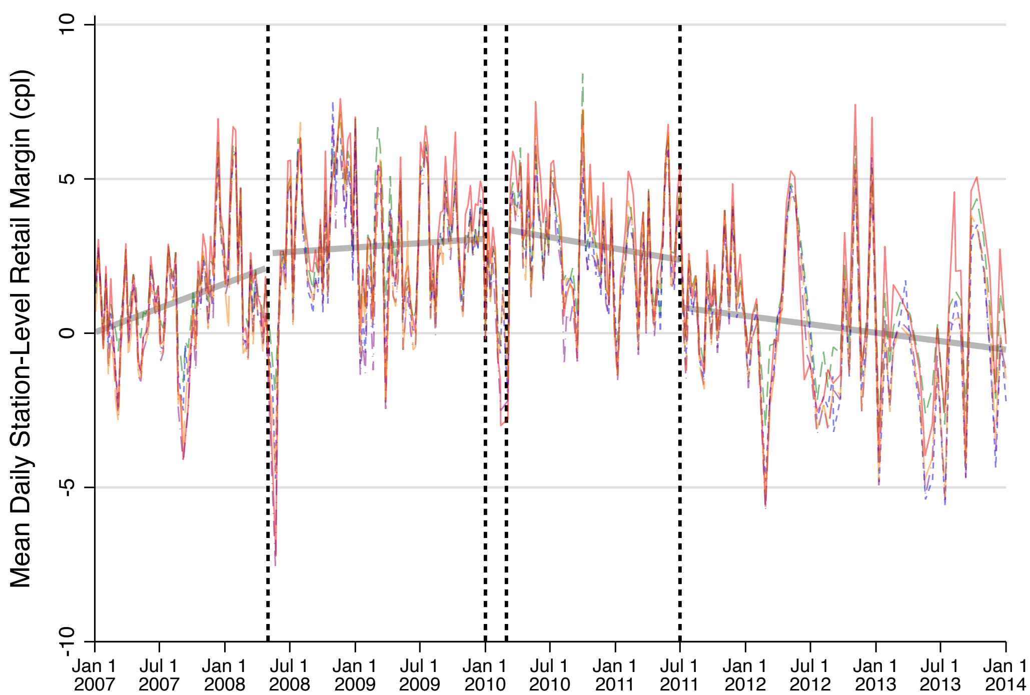
- In summary, the growth in cycle length in Figure 4 starting in July 2011 appears to be driven by: (1) undercutting prices until margins reach 0 at the bottom of the cycle, which is down from a bottom-of-cycle-margin of 2.5 cpl (Figure 16(b)); and (2) slower daily price undercutting which rises from approximately −1.5 cpl to −1 cpl in level between July 2011 and January 2014 (Figure 17). Higher restoration margins (which we would have seen in Figure 16(a)) do not appear to be a key driver of the longer cycles after July 2011 in Figure 4.

Figure 16: Evolution of Price-Cost Margins

(a) Margins at the **Top** of the Cycle

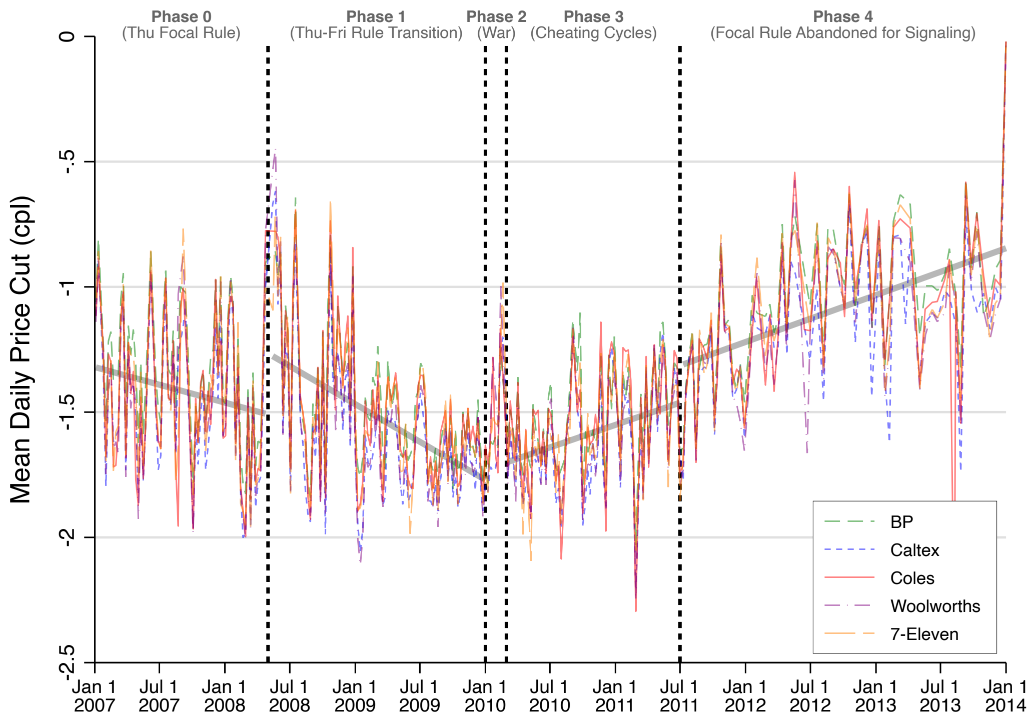


(b) Margins at the **Bottom** of the Cycle



Notes: Panels (a) and (b) respectively plot, by retailer and retailer-level cycle, the average of $\min(p_{ic})$ and $\max(p_{ic})$ where $\min(p_{ic})$ is the minimum price of station i in cycle c (bottom of the cycle), $\max(p_{ic})$ is the maximum price of station i in cycle c (top of the cycle), where station-level cycles are classified per Definition 1.

Figure 17: Rate of Daily Price Undercutting



Notes: The figure plots, by retailer and retailer-level cycle, the average of $\text{rate}_{ic} = \frac{\min(p_{ic})-\max(p_{ic})}{\text{length}_{ic}}$ where $\min(p_{ic})$ is the minimum price of station i in cycle c (bottom of the cycle), $\max(p_{ic})$ is the maximum price of station i in cycle c (top of the cycle), and length_{ic} is the length of station i's cycle c in days, per Definition 1. rate_{ic} is thus the slope of the undercutting phase for station i implementing cycle c.

5.2 Margins

Figure 18: Shares of Retail Volume Sold by Day of the Week

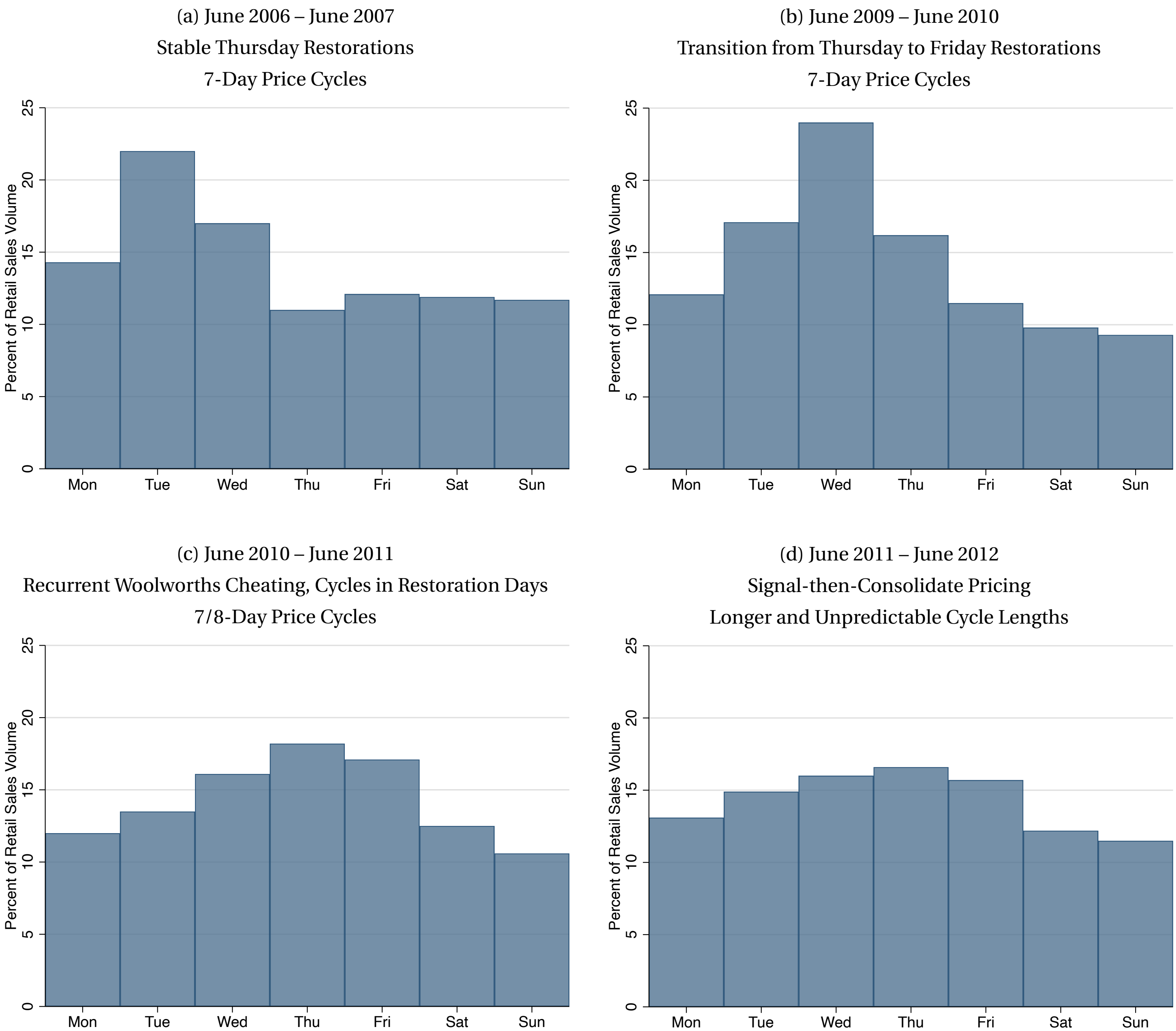
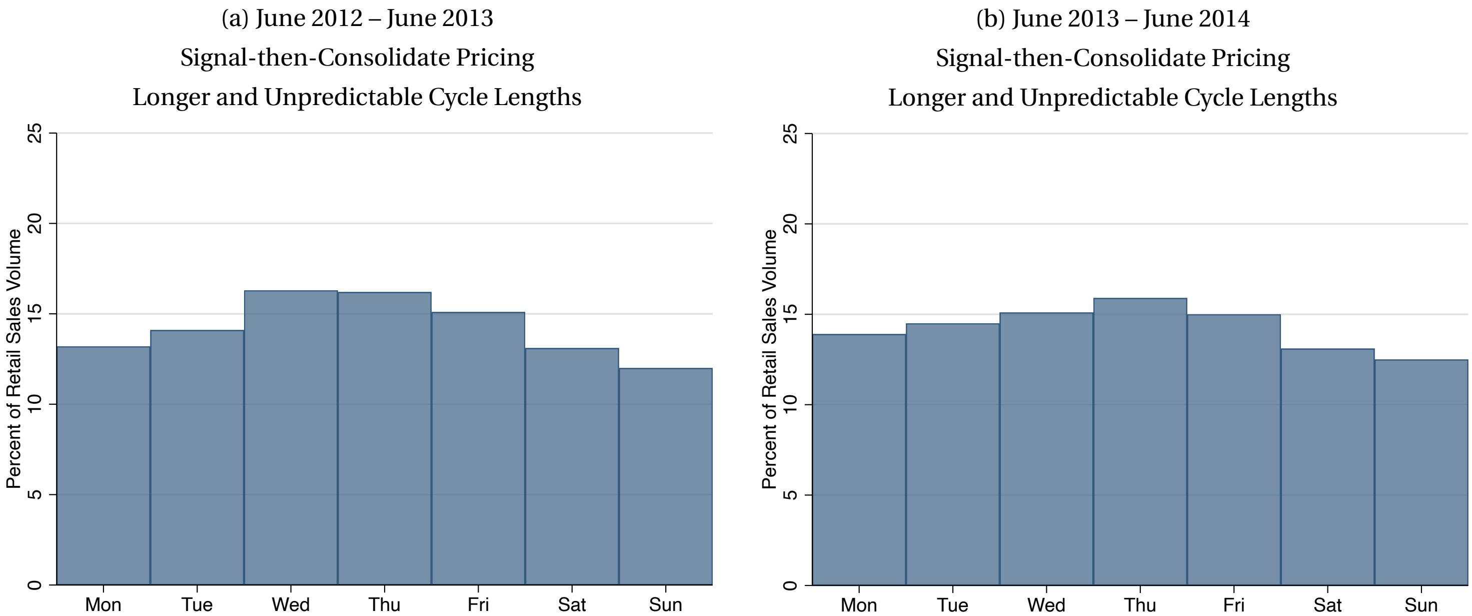


Figure 18: Shares of Retail Volume Sold by Day of the Week (cont.)



Notes: The figure plots the shares of fuel volumes sold by day of the week and year using data from ACCC industry monitoring reports in 2006, 2011, 2012, 2013, and 2014, which are based on fuel volume sold data provided to the ACCC by the gasoline retailers.

- estimate demand system
  - demand model from the asymmetric info sharing paper
  - OPIS data to estimate a demand system using 2016 data
  - figures of volume sold shares by day of the week from 2007 to 2014 ACCC reports under focal day pricing and non-focal day pricing
- compute margins
  - mean weighted margin for phases 1, 2, 3, 4 by retailer
  - plot weight average margins by month and retailer highlighting phases 1, 2, 3, 4
  - emphasize Woolworths business stealing and cheating and collateral damage to BP/Caltex
  - also highlight how evolution in the pricing structure over time simultaneously allows for signaling and stems the gains from cheating on rivals in coordinating restorations (i.e., there is a reduction in price leadership risk when moving from focal restoration days to signaling)
  - basically want to paint a picture of oligopolists using prices to negotiate over the division of profits over time
  - shortcoming is we can't estimate the associated profit effects in the grocery stores which gives Woolworths bargaining leverage in recurrently cheating
- price dispersion in appendix

6 Conclusion

This paper has studied how oligopolists use market prices to negotiate a collusive arrangement. Our forensic analysis has illustrated the depth of prices as a communication medium when firms share disaggregated, high-frequency, and strategic information on prices. Such a medium is sufficiently thick to enable the gradual and systematic evolution of anticompetitive pricing structures and the ability to resolve price wars without an explicit agreement.

Our results also highlight challenges with collusion supported by price-based communication. Without direct communication, firms have scope for testing and learning over the implicit rules to a collusive agreement. Such strategic uncertainty can give rise to periods of sustained cheating without punishment, particularly if punishments can create volatility and exacerbate strategic uncertainty in ways that compromise firms' willingness and ability to collude altogether.

References

ACCC (2008): "Monitoring of the Australian Petroleum Industry: Report of the ACCC into the Prices, Costs and Profits of Unleaded Petrol in Australia," December.

——— (2009): "Monitoring of the Australian Petroleum Industry: Report of the ACCC into the Prices, Costs and Profits of Unleaded Petrol in Australia," December.

——— (2010): "Monitoring of the Australian Petroleum Industry: Report of the ACCC into the Prices, Costs and Profits of Unleaded Petrol in Australia," December.

——— (2011): "Monitoring of the Australian Petroleum Industry: Report of the ACCC into the Prices, Costs and Profits of Unleaded Petrol in Australia," December.

——— (2012): "Monitoring of the Australian Petroleum Industry: Report of the ACCC into the Prices, Costs and Profits of Unleaded Petrol in Australia," December.

——— (2013): "Monitoring of the Australian Petroleum Industry: Report of the ACCC into the Prices, Costs and Profits of Unleaded Petrol in Australia," December.

——— (2014): "Monitoring of the Australian Petroleum Industry: Report of the ACCC into the Prices, Costs and Profits of Unleaded Petrol in Australia," December.

ARYAL, G., F. CILIBERTO, AND B. T. LEYDEN (2022): "Coordinated Capacity Reductions and Public Communication in the Airline Industry," *Review of Economic Studies*, 89, 3055–3084.

ASKER, J., C. FERSHTMAN, J. JEON, AND A. PAKES (2020): "A Computational Framework for Analyzing Dynamic Auctions: The Market Impact of Information Sharing," *RAND Journal of Economics*, 51, 805–839.

ASSAD, S., R. CLARK, D. ERSHOV, AND X. LEI (forth): "Algorithmic Pricing and Competition: Empirical Evidence from the German Retail Gasoline Market," *Journal of Political Economy*.

BACKUS, M., T. BLAKE, J. PETTUS, AND S. TADELIS" (2023): "Communication and Bargaining Breakdown: An Empirical Analysis," NBER working paper 27984.

BORENSTEIN, S. (2004): "Rapid Price Communication and Coordination: The Airline Tariff Publishing Case (1994)," in *The Antitrust Revolution: Economics, Competition and Policy*, ed. by J. Kwoka Jr. and L. White, Oxford University Press, 233–251.

BORENSTEIN, S. AND A. SHEPARD (1996): "Dynamic Pricing in Retail Gasoline Markets," *RAND Journal of Economics*, 27, 429–451.

BRANDENBURGER, A. (1996): "Strategic and Structural Uncertainty in Games," in *Wise Choices: Games, Decisions, and Negotiations*, ed. by R. Zeckhauser, R. Keene, and J. Sibenius, Harvard Business School Press, 221–232.

BROWN, Z. Y. AND A. MACKAY (2023): "Competition in Pricing Algorithms," *American Economic Journal: Microeconomics*, 15, 109–156.

BUSSE, M. R. (2000): "Multimarket Contact and Price Coordination in the Cellular Telephone Industry," *Journal of Economics and Management Strategy*, 9, 287–320.

BYRNE, D. P. AND N. DE ROOS (2017): "Consumer Search in Retail Gasoline Markets," *Journal of Industrial Economics*, 65, 183–193.

——— (2019): "Learning to Coordinate: A Study in Retail Gasoline," *American Economic Review*, 109, 591–619.

BYRNE, D. P., N. DE ROOS, A. R. GRINBERG, AND L. M. MARX (2024a): “Informed Sources and the Role of Platforms for Facilitating Anticompetitive Communication,” in *Cartels Diagnosed: New Insight on Collusion*, ed. by J. E. Harrington and M. P. Schinkel, Cambridge.

BYRNE, D. P., N. DE ROOS, M. S. LEWIS, L. M. MARX, AND X. WU (2024b): “Asymmetric Information Sharing in Oligopoly: A Natural Experiment in Retail Gasoline,” Working Paper, University of Melbourne.

CALVANO, E., G. CALZOLARI, V. DENICOLO, AND S. PASTORELLO (2020): “Artificial Intelligence, Algorithmic Pricing, and Collusion,” *American Economic Review*, 110, 3267–3297.

CILIBERTO, F. AND J. W. WILLIAMS (2014): “Does Multimarket Contact Facilitate Tacit Collusion? Inference on Conduct Parameters in the Airline Industry,” *RAND Journal of Economics*, 45, 764–791.

CLARK, R. AND J.-F. HOUDE (2013): “Collusion with Asymmetric Retailers: Evidence from a Gasoline Price-Fixing Case,” *American Economic Journal: Microeconomics*, 5, 97–123.

——— (2014): “The Impact of Explicit Communication on Pricing: Evidence from the Collapse of a Gasoline Cartel,” *Journal of Industrial Economics*, 62, 191–228.

COUNCIL OF ECONOMIC ADVISERS (2023): “Economic Report of the President,” Available at https://www.whitehouse.gov/wp-content/uploads/2023/03/erp-2023.pdf (accessed 27 November 2023).

CRAMTON, P. AND J. A. SCHWARTZ (2000): “Collusive Bidding: Lessons from the FCC Spectrum Auctions,” *Journal of Regulatory Economics*, 17, 229–252.

——— (2002): “Collusive Bidding in the FCC Spectrum Auctions,” *Contributions to Economic Analysis and Policy (Article 11)*, 1, 1–18.

CRAWFORD, V. P. (2017): “Let’s Talk it Over: Coordination via Preplay Communication with Level-k Thinking,” *Research in Economics*, 71, 20–31.

ECKERT, A. (2013): “Empirical Studies of Gasoline Retailing: A Guide to the Literature,” *Journal of Economic Surveys*, 27, 140–166.

ERUTKU, C. AND V. A. HILDEBRAND (2010): “Conspiracy at the Pump,” *Journal of Law and Economics*, 53, 223–237.

EZRACHI, A. AND M. E. STUCKE (2017): “Algorithmic Collusion: Problems and Counter-Measures,” Roundtable on Algorithms and Collusion at the OECD Competition Committee.

FARRELL, J. AND M. RABIN (1996): “Cheap Talk,” *Journal of Economic Perspectives*, 10, 103–118.

GENESOVE, D. AND W. MULLIN (2001): “Rules, Communication, and Collusion: Narrative Evidence from the Sugar Institute Case,” *American Economic Review*, 91, 379–398.

GREEN, E. J. AND R. H. PORTER (1984): “Noncooperative Collusion under Imperfect Price Information,” *Econometrica*, 52, 87–100.

HARRINGTON, J. (2017): “A Theory of Collusion with Partial Mutual Understanding,” *Research in Economics*, 71, 140–158.

HOLT, T., M. IGAMI, AND S. SCHEIDEGGER (2024): “Detecting Edgeworth Cycles,” *Journal of Law and Economics*, 67, 67–102.

HOUDE, J.-F. (2012): “Spatial Differentiation and Vertical Mergers in Retail Markets for Gasoline,” *American Economic Review*, 105, 2147–2182.

KNITTEL, C. R. AND V. STANGO (2003): “Price Ceilings as Focal Points for Tacit Collusion: Evidence from

Credit Cards," *American Economic Review*, 93, 1703–1729.

LEISTEN, M. (2022): "Algorithmic Competition, With Humans," Working Paper, U.S. Federal Trade Commission.

LEMUS, J. AND F. LUCO (2021): "Price Leadership and Uncertainty about Future Costs," *Journal of Industrial Economics*, 69, 305–337.

LEVENSTEIN, M. C. AND V. Y. SUSLOW (2006a): "What Determines Cartel Success?" *Journal of Economic Literature*, 44, 43–95.

——— (2006b): "What Determines Cartel Success?." *Journal of Economic Literature*, 44, 43–95.

LEWIS, M. S. (2012): "Price Leadership and Coordination in Retail Gasoline Markets with Price Cycles," *International Journal of Industrial Organization*, 30, 342–351.

——— (2015): "Odd Prices at Retail Gasoline Stations: Focal Point Pricing and Tacit Collusion," *Journal of Economics and Management Strategy*, 24, 664–685.

LUCO, F. (2019): "Who Benefits from Information Disclosure? The Case of Retail Gasoline," *American Economic Journal: Microeconomics*, 11, 277–305.

MARSHALL, R. C. AND L. M. MARX (2012): *The Economics of Collusion: Cartels and Bidding Rings*, MIT Press.

MILLER, N., M. WEINBERG, AND G. SHEU (2021): "Oligopolistic Price Leadership and Mergers: The United States Beer Industry," *American Economic Review*, 111, 3123–3159.

MUSOLFF, L. (2022): "Algorithmic Pricing Facilitates Tacit Collusion: Evidence from E-Commerce," Working Paper, Microsoft Research.

STIGLER, G. J. (1964): "A Theory of Oligopoly," *Journal of Political Economy*, 72, 44–61.

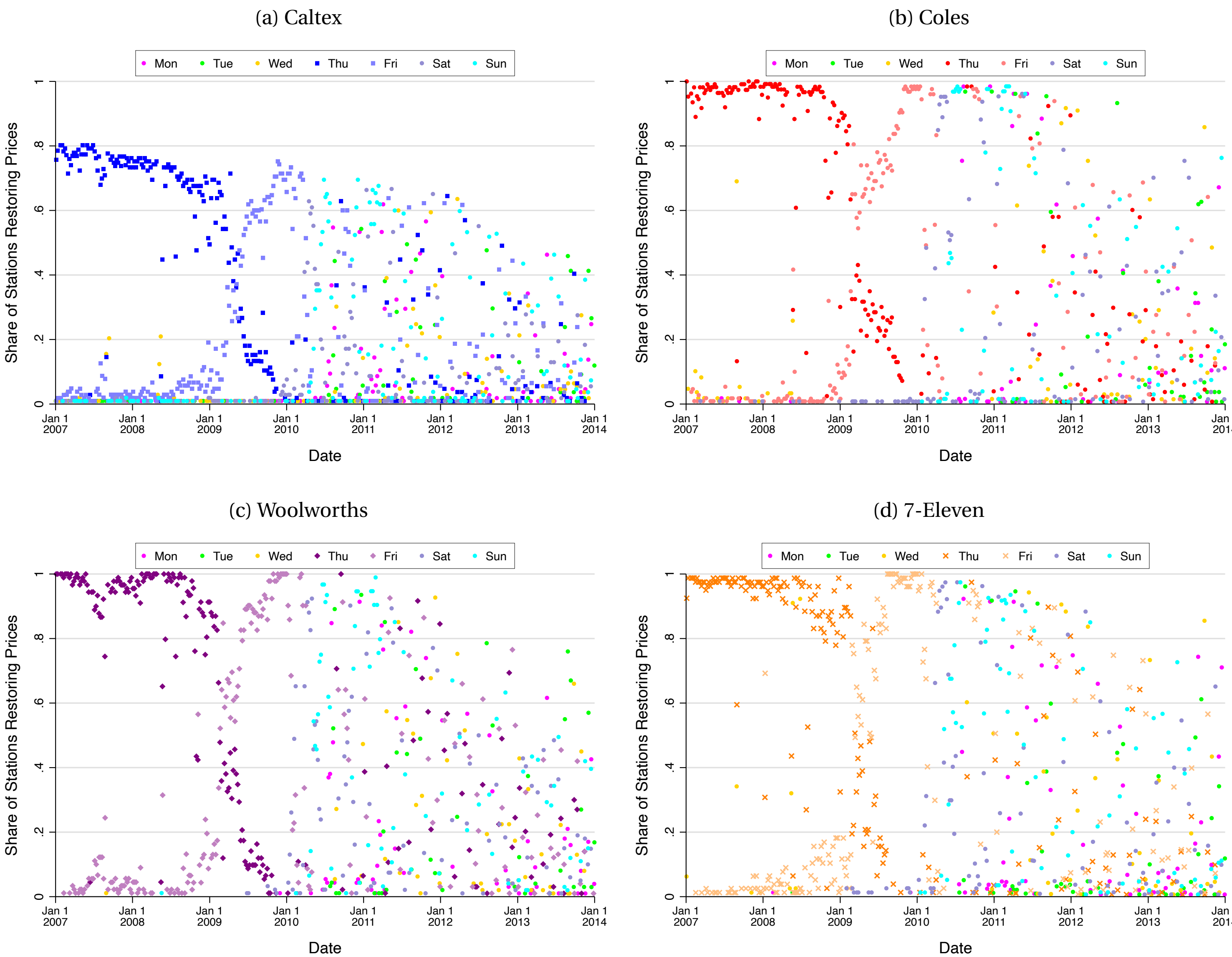
WANG, Z. (2009): "(Mixed) Strategy in Oligopoly Pricing: Evidence from Gasoline Price Cycles Before and Under a Timing Regulation," *Journal of Political Economy*, 117, 987–1030.

WU, X., M. S. LEWIS, AND F. A. WOLAK (2024): "Search with Learning in the Retail Gasoline Market," *RAND Journal of Economics*.

Online Appendix

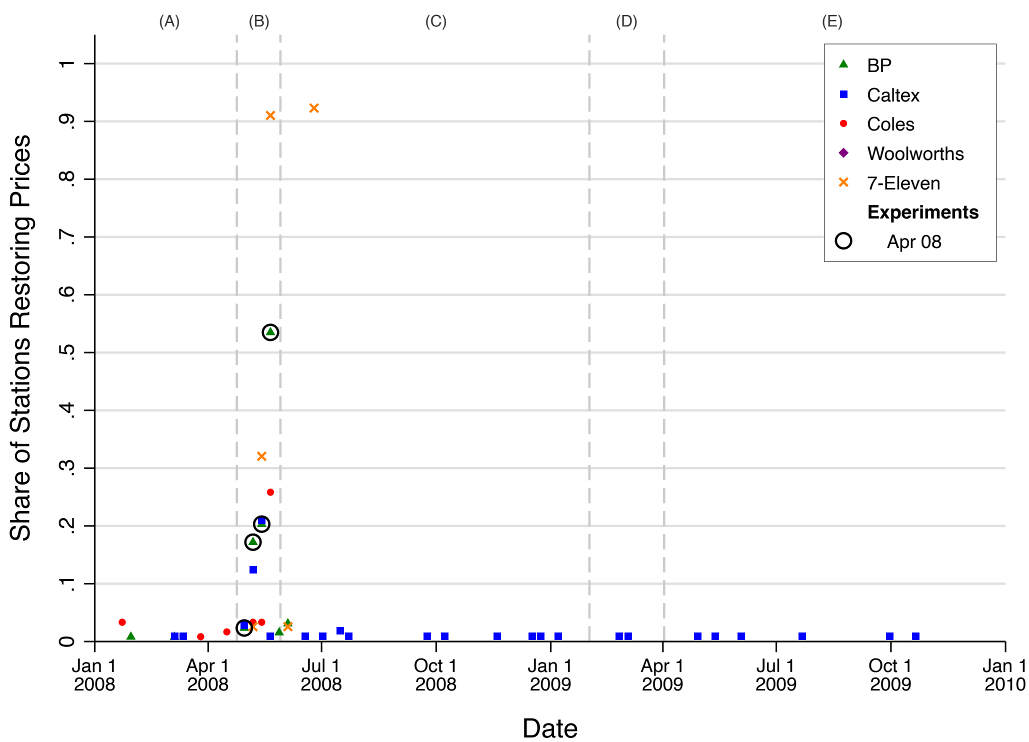
A Supplemental results

Figure A.1: Restoration Timing for Rivals Before and After the Case Settlement



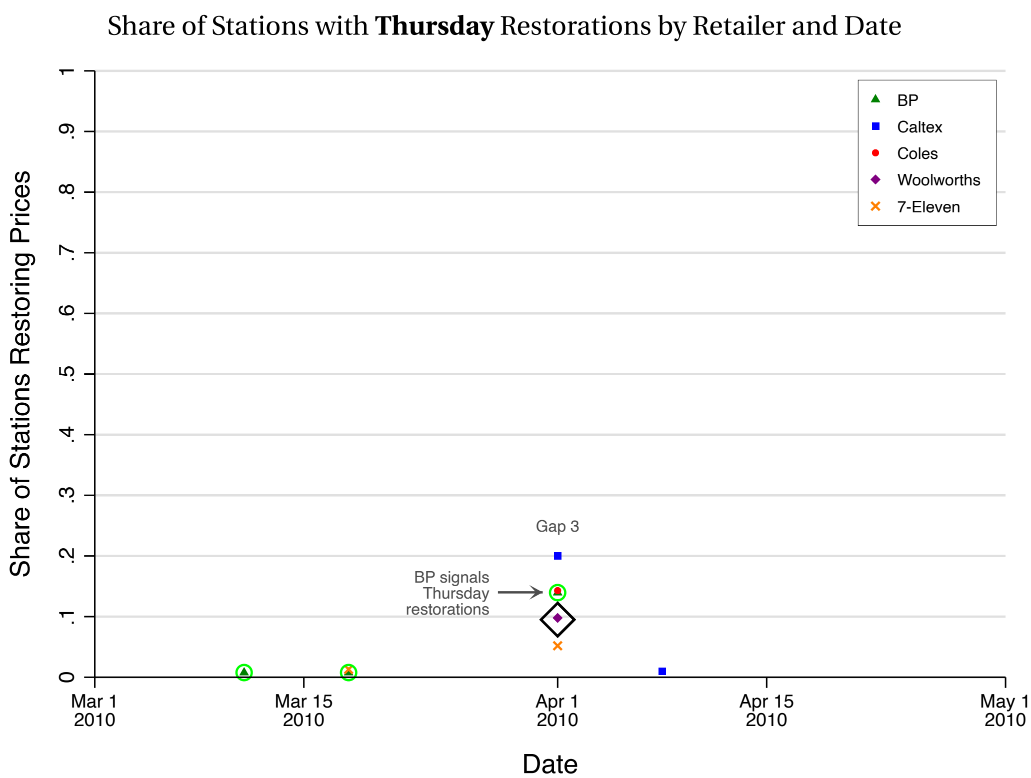
Notes: The figure plots the share of Caltex, Coles, Woolworths, and 7-Eleven stations engaging in station-level price restorations per Definition 1(i) by day of the week between 2007 and 2014.

Figure A.2: Share of Stations with **Wednesday** Restorations by Retailer and Date



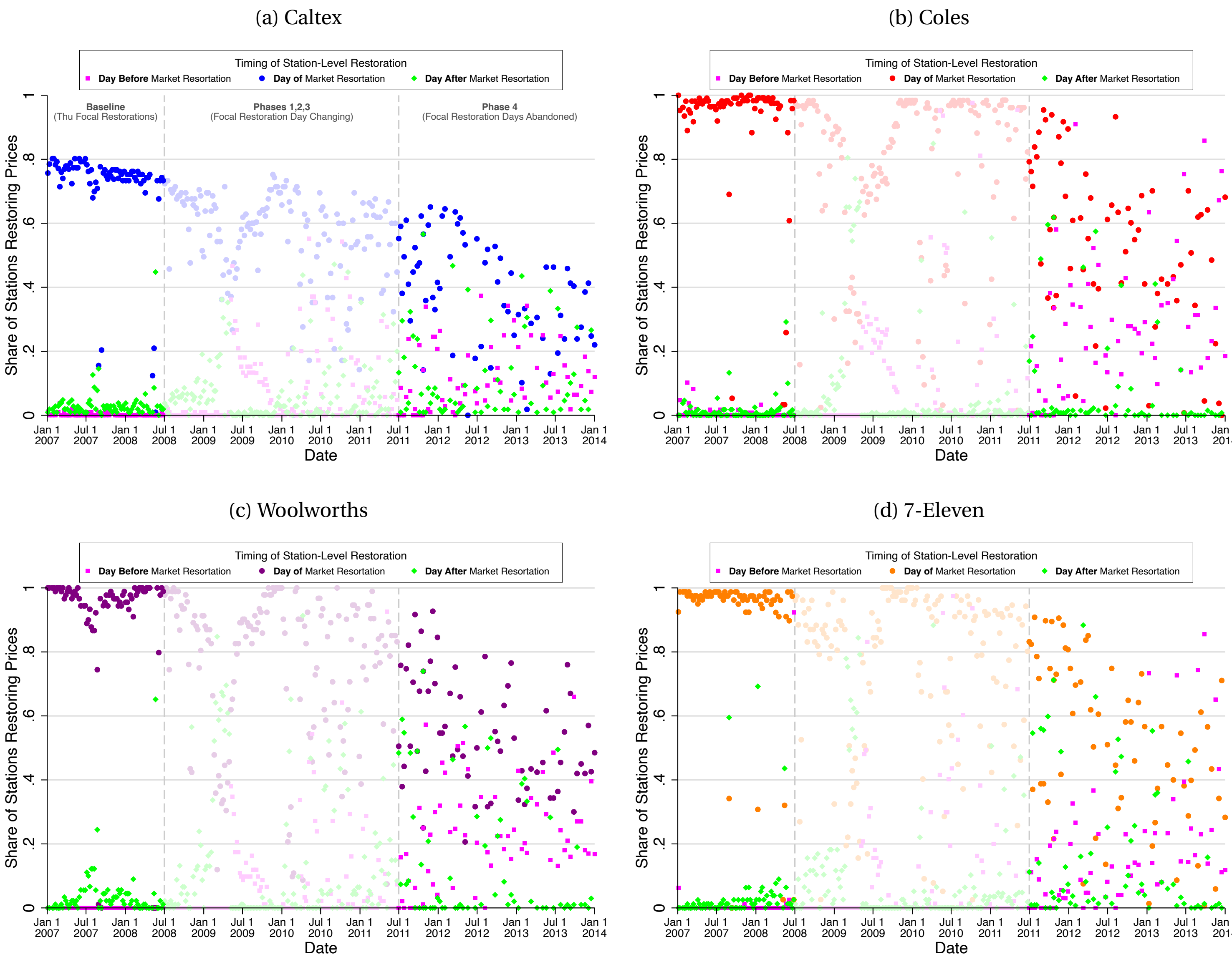
Notes: The figure plots the share of stations engaging in station-level price restorations per Definition 1(i) on Wednesdays by retailer between January 1, 2007, and January 1, 2010.

Figure A.3: Recurrent Cheating on Focal Restoration Days



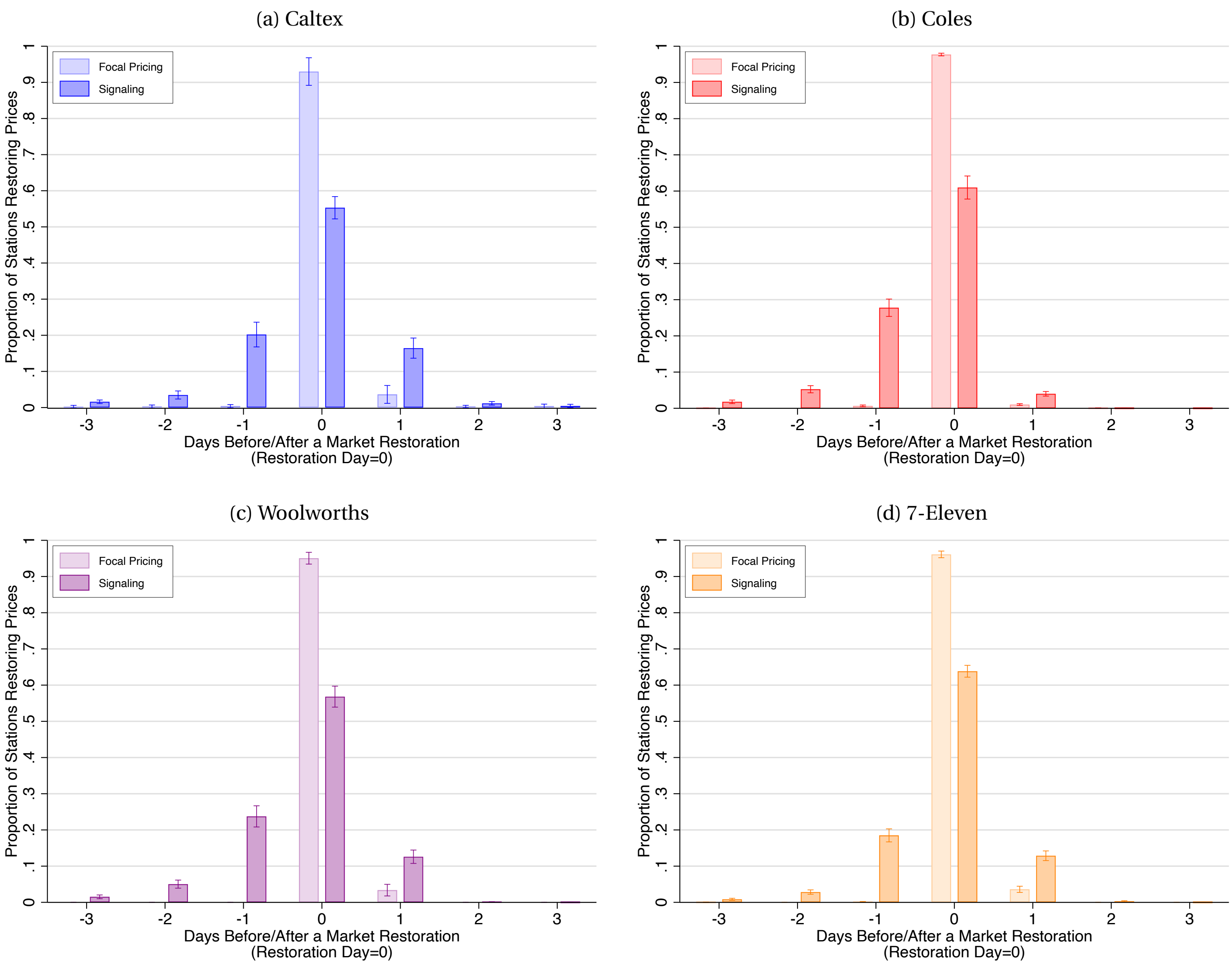
Notes: The figure plots the share of BP, Caltex, Coles, Woolworths, and 7-Eleven stations engaging in station-level price restorations per Definition 1(i) on Thursdays between March 1, 2010, and May 1, 2010.

Figure A.4: Restoration Timing for Rivals Before and After the Case Settlement



Notes: Panels (a)–(d) in the figure plot respectively plot the shares of Caltex, Coles, Woolworths, and 7-Level stations engaging in station-level restorations the day before, day of, and day after market-level restorations between January 1, 2009, and January 1, 2014, per Definitions

Figure A.5: Station-Level Restoration Timing Under Focal Pricing and Price Signaling



Notes: The figure plots estimates from our restoration timing linear in probability model (1) for Caltex, Coles, Woolworths, and 7-Eleven.