Retail Gasoline Price Cycles: Evidence from Guelph, Ontario Using Bi-Hourly, Station-Specific Retail Price Data

by

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Abstract

The purpose of this paper is to use price data directly observed eight times per day for 103 days at 27 gasoline stations in Guelph, Ontario, to examine several basic predictions of a theory of price cycles (Edgeworth cycle theory). It is found that price movements in Guelph are largely consistent with this theory and less consistent with other dynamic pricing theories. Also, the data identify some interesting (and rather predictable) pricing patterns that would likely be overlooked with less complete data, and which offer guidance for how the Edgeworth cycle theory might be refined to make more accurate predictions.

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1. Introduction

In several cities in Canada, the United States, and Australia, retail gasoline prices appear to move in cycles where they rise by large amounts in one or two days, followed by several days of small consecutive price decreases. Some consumers and politicians cite these cycles as evidence of anti-competitive behavior, while others argue that such price volatility is an indication of intense competition. Thus, a clear understanding of the dynamics behind these cycles has important implications for both economists and policymakers.

The Edgeworth cycle theory, which will be reviewed in Section 2, has often been used to explain these cycles, but the limitations of publicly available data tend to restrict researchers to infrequently collected average price data, or station-specific prices for a subset of stations in a market. These data might generate misleading conclusions regarding which types of stations tend to lead price increases, which types tend to either match or undercut their rivals' prices, and even whether prices cycle at all.

Thus, the purpose of this paper is to examine the accuracy of several basic predictions of the Edgeworth cycle theory using bi-hourly retail prices that were directly observed at 27 gas stations in Guelph, Ontario between August 14 and November 24, 2005. Wholesale (rack) prices were obtained for London, Ontario to approximate marginal costs, and certain station characteristics were also observed in the field.

To anticipate results, the data are largely consistent with the basic predictions of the Edgeworth cycle theory and less consistent with alternative explanations of cycles. Also, some interesting patterns have been observed in the data that would likely be overlooked with less complete data, and which provide guidance for how the theory might be refined to make more accurate predictions. First, it appears that only a certain independent brand tends to set the city-wide minimum price in Guelph, rather than independents in general; this finding suggests that higher concentration or market shares of independents might not necessarily lead to lower prices in a market. Second, the identities of the leaders of price increases, as well as the timing and sizes of their increases, tend to be quite predictable; this predictability might increase the probability that a station's price increase will be followed by its rivals, as well as increase the speed of its rivals' responses.

This paper is organized as follows. The Edgeworth cycle theory and its testable implications are

reviewed in Section 2, as is the relevant empirical literature. Section 3 discusses the data, Section 4 examines the accuracy of several basic predictions of the Edgeworth cycle theory, and Section 5 considers alternative theoretical explanations of price cycles. Section 6 addresses whether price movements following Hurricane Katrina are consistent with the basic predictions of the Edgeworth cycle theory, and Section 7 concludes.

2. Literature Review

2.1. Edgeworth Cycle Theory

In the alternating-moves model developed by Maskin and Tirole (1988), two identical firms maximize their present-discounted stream of profits by setting prices for a homogeneous product over an infinite horizon. Marginal cost is constant, there are no fixed costs or capacity constraints, and the lowest-priced firm serves the entire market. If both prices are equal, then they split market demand evenly. Price competition occurs in discrete time, and prices are chosen over a finite grid. Finally, a firm's strategies depend only on the most recent price set by its rival. Using this framework, Maskin and Tirole (1988) prove that for a sufficiently fine price grid and a discount factor near one, many Markov perfect equilibria exist, including Edgeworth cycles.[1]

The structure of an equilibrium cycle is shown graphically in Figure 1, and is described as follows. Beginning at the top of the cycle, a firm undercuts its rival's price by one unit; this strategy is played by the firm because it expects its rival to do the same in the next period, and because it can serve the entire market before its rival responds to this undercut. These one-unit undercuts continue until one firm lowers its price to marginal cost. There is then a war of attrition of indeterminate length as each firm waits with positive probability for the other to initiate a cycle "restoration" by raising its price to the new cycle peak, after which the cycle is repeated. This reluctance to lead a restoration is not because it might not be followed,[2] but rather

[1] Noel (2006) computationally extends this model to permit randomly fluctuating marginal cost, and finds Edgeworth cycle equilibria with product/spatial differentiation, capacity constraints and three firms.

[2] In the two-firm model, a price increase will always be followed by the leader's rival in the next period, so there is no coordination problem. However, Noel (2006) shows computationally that if the model

due to the expectation that the follower will undercut this price incrementally, causing the leader to make zero profits for two consecutive periods.[3] Furthermore, the leader sets a price *above* the monopoly price so that its profits will be closer to the monopoly level when it does have the opportunity to set its price again.

Eckert (2003) extends the basic model to allow the two firms to differ in size, which can be measured by the number of stations each one operates in the market; if both firms charge the same price, their shares of market demand are proportional to their relative sizes. He uses examples to demonstrate that the large firm will tend to lead price increases and follow a price matching strategy when prices fall, while the small firm is more likely to follow an undercutting strategy. Intuitively, although there is no coordination problem in this model, a large firm can more easily coordinate a restoration by simultaneously raising all of its stations' prices. As for price decreases, the market sharing rule is biased in favor of the large firm, so it prefers to match its rival's price, while the small firm prefers an undercutting strategy.

Based on the above theory, the following basic predictions will be examined in this paper, where Structural Predictions (S1) to (S5) relate to the prices being set, and Behavioral Predictions (B1) to (B2) describe how stations are expected to interact with their rivals (and so require station-specific price data):[4]

(S1) As demonstrated in Figure 1, retail prices tend to rise by large amounts in a short amount of time, and then fall over a longer amount of time with a series of much smaller decreases.

(S2) Prices cycle even if marginal cost is constant. Thus, the rack price series is not expected to follow the asymmetric pattern described in Prediction (S1).

(S3) Prices do not rise until a station's price falls to marginal cost, so it initiates a restoration when, and only when its price approaches marginal cost.

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is extended to include three firms, then a firm might abandon its restoration attempt if its lead is not followed quickly enough by its rivals. Noel (2006) calls these failed attempts "false starts".

[3] The knowledge that leading a restoration will result in two consecutive periods of zero profits also discourages firms from raising their prices before they equal marginal cost.

[4] Identifying predictions as being either "structural" or "behavioral" is adopted from Noel (2007).

(S4) The leader of a price increase will set its price just above the monopoly price to maximize its present-discounted stream of profits over the new cycle.

(S5) Firms undercut one another by minimal amounts in a battle of market share, so the magnitudes of retail price decreases are expected to *not* vary with the cycle position.

(B1) Based on examples provided by Eckert (2003) and intuition, price increases will tend to be led by brands that individually control prices at more stations than other brands (the majors).

(B2) Based on the same examples and intuition, the stations that undercut the market minimum price will tend to be brands that control prices at relatively few stations (independents).

2.2. Empirical Studies

The Edgeworth cycle theory has been used to explain retail gasoline price cycles in Canada (e.g., Eckert, 2002), the U.S. mid-west (e.g., Lewis, 2006), and Australia (e.g., Wang, 2006a). However, these studies tend to use prices that are either averaged across stations, or in the case of Wang (2006a), collected for a market where the timing of price changes is regulated by the Western Australian government, and so cannot be used to study inter-station price competition in an unregulated market.

On the other hand, Noel (2007) econometrically finds support for Predictions (B1) and (B2), among other Edgeworth cycle predictions, using prices that were directly observed at 22 gasoline stations in Toronto every 12 hours for 131 days in 2001. However, the author appears to be unable to identify consistent price leaders (if they exist) because several different stations tended to raise their prices in the same 12-hour period, making it difficult to identify which station(s) moved first.

With respect to specific brands that might be instrumental in driving prices down in gasoline markets, using station-specific price data collected from gasoline price websites in Ottawa and Vancouver, Eckert and West (2004a) find evidence that the existence of cycles seems to depend on the presence of suspected

"maverick" retailers that prevent tacit collusion, such as Sunoco and Pioneer in Ottawa,[5] and ARCO and Tempo in Vancouver. Similarly, Eckert and West (2004b) find that price decreases in Vancouver appear to originate in regions where ARCO and Tempo are most highly concentrated.[6]

Evidence in the literature also suggests that the timing and sizes of price increases can be predictable. For example, Eckert and West (2004b) demonstrate graphically that the wholesale price and mode peak price in their data are both quite stable, implying that peak margins are relatively constant; Noel (2007, 85) also finds evidence that stations in Toronto tend to raise their prices to an "almost standard markup". With respect to the timing of price increases, the Conference Board of Canada (2001, 28) claims that prices tend to rise early in the week (after the morning rush) when demand is relatively low, and evidence consistent with the day-of-the-week part of this claim is presented by Eckert and West (2004b) and Noel (2007).

Finally, Wang (2006b) empirically examines the coordination problem in the context of a 2004 antitrust case involving gas stations in Ballarat, Australia. In this case, phone records show that inter-station phone calls increased substantially on days when restorations were initiated in 1999 and 2000; these phone calls were allegedly initiated to coordinate price increases. However, no studies have been found which focus on how prices movements might facilitate the coordination of restorations without explicit collusion.

3. The Data

Regular-grade fuel prices in cents per liter (cpl) were collected bi-hourly (8:00AM to 10:00PM) from August 14 to November 24, 2005 for 27 stations in Guelph,[7] a city in southern Ontario with a population of 106,000.

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[5] Eckert and West (2004a) also note that Suncor owns both the Sunoco brand and 50% of Pioneer.

[6] Using monthly data on average retail prices and individual firm market shares for 11 Canadian cities between 1991 and 1997, Sen (2005) finds that average prices tend to be lower in the cities where smaller (independent) firms are more highly concentrated or have higher market shares. However, the author does not identify any specific brands as leading price decreases, nor does he focus directly on price cycles.

[7] The last period during which prices were collected on November 24 began at 4:00PM.

All 27 prices were collected once in 45 minutes, on average. Station characteristics were also collected, including operating hours (24 hours or not), service levels (full-, self-, or split-serve), capacities (regular-grade nozzle counts), and other operations (repair bay, convenience store, car wash). Finally, daily rack price data for London, Ontario were obtained from MJ Ervin & Associates to approximate marginal costs.

Station locations are plotted in Figure 2, and numbered in the order that they were collected.[8] Esso, Petro-Canada, Shell/Beaver and Sunoco are the vertically-integrated (major) brands in the city; Canadian Tire, 7-Eleven and Pioneer are among the independents in the city, where an independent is defined as a brand that is not 100% owned by a refiner brand. Selected characteristics for each station are provided in Table 1, where it can be seen that major brand stations tend to be 24-hour, self-serve stations with relatively high capacities, convenience stores and car washes, and no repair bays. Stations selling gasoline under the 7-Eleven, Canadian Tire, and Pioneer brands are similar to these major brand stations in terms of capacities and other characteristics, while the other independents are full-serve stations with lower capacities, limited hours, and repair bays, but no other non-gasoline operations.

Intuitively, the ability of a brand to successfully lead a restoration can depend on the number of stations' prices that it controls, and the locations of these stations. Thus, representatives of the above seven brands were contacted, and six reported that each station's price is company-controlled (Station 14's manager is permitted some control over its price); Esso refused to provide price control information. However, MJ Ervin & Associates Inc. (2006, Appendix A) reports that 7-Eleven Canada controls prices at its Esso-branded stations, implying that Station 7's price is not controlled by Esso. Also, Station 17 is described on an Esso-affiliated website as a family-operated dealer.[9] Finally, the empirical literature on station contracts suggests

[8] Esso Station 28 was excluded from the sample because it did not post its price. However, prices collected directly from its pump once per night from August 14 to September 29, 2005 (excluding August 16) suggest that the other 27 stations were not reacting to its price movements; on average, Station 28's price is observed to change every 9.0 days versus every 1.0 to 2.0 days for each of the other 27 stations in Guelph.

[9] See "Esso Rebecca Run for SMA" (http://www.rebeccarun.com/esso_dealers/rainbow.html; visited 2007-10-18).

that a company is more likely to control prices at stations with longer hours, greater pump capacities, or convenience stores, and is more likely to delegate price-setting authority to stations that are full-serve and/or have repair bays.[10] Based on these conclusions, major brand stations are divided in Table 1 by the likely source of price control, where Group A stations' prices are either known or believed to be controlled by the head office of the brand, and Group B stations' prices are not. Independents are separated into groups by capacities (regular-grade nozzle counts), where Group C stations have more nozzles than Group D stations.

Finally, it appears that all relevant competitors of each station in Guelph are included in the sample, so price leaders can be confidently identified. Specifically, the 10 nearest stations to Guelph are located 1.9 to 6.4 miles from their nearest Guelph neighbors, and the area surrounding Guelph is non-residential (see Figure 3). Thus, if gasoline consumers patronize stations near their homes,[11] then they likely do not view these 10 stations as relevant alternatives to Guelph stations.

4. Empirical Examination of the Basic Theoretical Predictions

4.1. Structural Predictions

The five basic structural predictions described in Section 2.1 will be examined in this subsection using the following definitions. First, modifying the definition of Eckert and West (2004b), an attempted restoration day (Day 0) is a day when the bi-hourly, city-wide mode price rises after a station raises its price to that mode;[12] subsequent days are labeled Day 1, 2, etc. This methodology yields 16 restoration attempts. Second, a restoration phase begins during the period that a restoration attempt is identified, and ends during the period

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[10] For example, see Shepard (1993), Slade (1998), and Taylor (2000).

[11] For example, in his Affidavit for the case of *Director of Investigation and Research v. Imperial Oil Limited*, dated July 24, 1989, Exhibit A at paragraph 14, Professor M. Trebilcock writes that "industry data suggest that up to 70% of consumers tend to buy most of their gasoline within two miles of their homes." This quote also appears on pages 22-23 of the Reasons and Decision for the case.

[12] Mode price increases in a single period are occasionally observed after a station lowers its price, causing a higher price to be more frequently observed, and are clearly not restoration attempts.

when the last station is observed to set its cycle peak; the rest of the cycle is the undercutting phase.[13]

4.1.1. Basic Patterns in Retail Price Changes

The purpose of this subsection is to demonstrate that retail gasoline prices in Guelph follow an asymmetric pattern, increasing by large amounts in a short amount of time and then falling over a longer amount of time with a series of much smaller price decreases, consistent with Prediction (S1). These structural patterns are summarized numerically in Table 2, and explained as follows.

First, the data indicate that retail gasoline prices in Guelph fall much more frequently than they rise. On average, an individual station's price falls 5.5 times more often than it rises (116 vs. 21 times), while the daily city-wide mean and mode prices fall 3.1 and 4.3 times more often than they rise, respectively.

Table 2 also shows that price increases tend to be much larger in magnitude than price decreases. In an average period, individual station price increases are 5.2 times greater than decreases (7.3 cpl vs. 1.4 cpl), while daily city-wide mean (mode) price increases are 2.9 (4.1) times greater than decreases.

Finally, restoration phases in the Guelph data tend to be much shorter in duration than undercutting phases; as seen in Table 2, the average undercutting phase is 4.2 times longer than the average restoration phase (5.0 days vs. 1.2 days). Also, restoration phases account for 89.2% of the 575 increases observed in the data, which is consistent with the prediction that prices will tend to fall during undercutting phases,[14] with

[13] Note that only a subset of the 27 stations in the sample are observed to raise their prices during five of these 16 cycles. Two of these five restorations appear to be false starts (see Noel, 2006, *supra* note 2), since on average, only 21 stations are observed to raise their prices, and most price increases are reversed by the end of the Day 1. During a third cycle, only seven stations are observed to raise their prices, and they raise them to ones that are less than or equal to the pre-restoration prices of 14 other stations. Finally, only 26 stations are observed to raise their prices during each of the other two cycles.

[14] Another 3.1% of all increases are observed on September 22, but appear to be due to a temporary demand shock rather than a restoration phase. Queues of over 10 vehicles were observed at most stations in Guelph for the entire day, which formed before the first price increase; all but one increase was reversed by the next morning. Similar queues (and larger price increases) were reported in the media for stations across southern Ontario, and were attributed to consumer fears that gas prices would rise due to Hurricane Rita. The Competition Bureau also argues that "the spike in prices resulted from retailers responding to a

the possible exception of "step-ups".[15]

These findings are summarized graphically in Figure 4, in which the bi-hourly mode price is plotted with the London rack price and par Edmonton crude price.[16] As seen in this figure, the bi-hourly mode price tends to rise by much larger amounts than it falls, and restoration phases are usually much shorter in duration than undercutting phases. Finally, prices changes during undercutting phases are typically negative.

4.1.2. Basic Patterns in Rack Price Changes

The next step in assessing the applicability of the Edgeworth cycle theory to retail gasoline cycles in Guelph is to demonstrate that the London rack price is not characterized by the asymmetric patterns demonstrated above in the retail price. Such results would be consistent with Prediction (S2), which is that the retail price cycles will be observed even if marginal cost is constant.

First, Table 2 shows that the London rack price decreases only 1.4 times more often than it increases (39 vs. 28 times), compared to 4.3 times for the daily mode retail price, and 5.5 times for the average individual station. Similarly, on average, rack price increases are 1.1 times greater in magnitude than rack price decreases (2.4 cpl vs. 2.1 cpl), compared to 4.1 times for the daily mode retail price and 5.2 times for the average individual station. Thus, while the rack price does exhibit some asymmetry, it does not resemble the highly asymmetric cycles observed in Guelph retail prices.

It can next be established that while retail price changes in each direction tend to be followed by

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large increase in demand based on consumer fears of a potential shortage and price increases". See "Competition Bureau Concludes Examination into Gasoline Price Spike Following Hurricane Katrina" (http://www.competitionbureau.gc.ca/internet/index.cfm?itemID=2047&lg=e; visited 2007-10-18).

[15] Noel (2006) finds that if one firm is recognized by its rival as a consistent price leader, then it might follow a "step-up" strategy during an undercutting phase, where it raises its price slightly at the bottom of the cycle to remain profitable, and to also encourage its rival to lead the restoration. Step-ups are not predicted in equilibrium, but evidence of them has been found in the Guelph data.

[16] Daily crude oil price data (par Edmonton) were obtained from Natural Resources Canada (http://www2.nrcan.gc.ca/es/erb/prb/english/View.asp?x=476; visited 2007-10-18).

price decreases, there is no strong pattern with respect to the sign of rack price changes. Specifically, rack price increases are followed in the next price change by further increases 6.0 times more often than mode retail price increases are followed by increases. Also, rack price decreases are followed by increases 1.5 times more often than mode retail price decreases are followed by increases. Thus, it seems that while retail prices tend to fall during the cycle, rack prices exhibit no similarly strong pattern in either direction.

4.1.3. The Timing of Restoration Attempts

Although the Edgeworth cycle theory predicts that the cyclical patterns demonstrated in Section 4.1.1 are not driven by cost movements, it does predict that the *timing* of restoration attempts depends on the proximity of retail prices to marginal cost. Thus, using retail-rack margins,[17] this subsection will examine Prediction (S3) that restorations will be initiated when, and only when at least one firm's price falls to marginal cost.

Initially, it appears that while the data are generally consistent with this prediction, a minority (25%) of all 16 restoration attempts occur when the mode retail-rack margin in Guelph is still positive.[18] However, further investigation reveals that the data are always consistent with Prediction (S3) if restoration attempts are viewed as being initiated *regionally*. Using station-specific retail price data collected every 12 hours from OntarioGasPrices.com for three neighboring cities (Kitchener, Cambridge, and Waterloo),[19] it is found that restorations are always initiated in all four cities within two weekdays of the periodic mode retail-rack

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[17] The retail-rack margin equals the retail price minus the current London rack price, the Ontario provincial gasoline excise tax (14.7 cpl), the federal gasoline excise tax (10.0 cpl), and the federal Goods and Services Tax (7%), which is levied on both the price and the excise taxes.

[18] A margin is considered non-positive if it is strictly lower than 0.1 cpl, since it equals zero if it is rounded down to the next tenth-of-a-cent. Also, modes are calculated instead of means because they are representative of the posted prices of the first stations to raise their prices.

[19] Consumers voluntarily post the brands, locations and prices of gasoline retailers on this site. Both the alias of the "price spotter" and the time of their post are also listed. Membership is free and anonymous (but not required), and members earn points for posting prices and for participating in other features of the site; these points can be used to enter raffles for prizes such as U.S.$250 gas cards.

margin becoming non-positive in at least one of these cities.[20] Restorations observed in Guelph on Day 0 are always observed in all three other cities by the morning of Day 1, the mode peak price observed in Guelph is always observed for several stations in each other city, and restorations are *never* observed in any city if all four mode margins are positive. Since brands might delegate price-setting authority for several stations within a region to a single district manager, these findings are not inconsistent with Prediction (S3).

Another interesting finding regarding the timing of restoration attempts is that they tend to be initiated early in the week and during the middle of the day when gasoline demand is believed to be at a weekly low, consistent with empirical findings of studies discussed in Section 2. Specifically, 13 (81.3%) of the 16 restoration attempts are observed between Monday and Wednesday, and none on weekends. Also, the first stations to raise their prices to their peaks *always* do so between noon and 2:00PM, which is when travel demand in Guelph is relatively low.[21] In fact, restoration attempts are never observed in Guelph on weekdays after 2:00PM or on weekends, even when the bi-hourly mode retail-rack margin is negative.

The relationship between the timing of restoration attempts and the London rack price is summarized graphically in Figure 4, where the vertical lines that identify each Day 0 tend to be farther apart (closer together) when the rack price is falling (rising). Specifically, when the rack price is relatively stable (eight restorations), the average duration between restoration attempts is 6.1 days, which approximates the 6.2 day average duration in Table 2. However, when large rack price increases following Hurricanes Katrina and Rita reduce margins closer to zero, the average duration between restoration attempts is shorter (2.0 days for three restorations). Finally, when the London rack price trends downward, and thus margins remain positive longer, then the average duration between restoration attempts is longer (11.3 days for four restorations).

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[20] Mode prices are calculated bi-hourly for Guelph and 12-hourly for the other three cities.

[21] See Paradigm Transportation Solutions Limited *et al.* (2005, 20). Travel demand is considered to be a reasonable proxy for gasoline demand because consumers travel to buy gas.

4.1.4. The Predictability of Cycle Peaks

In addition to predicting when a restoration will likely be attempted, the Edgeworth cycle theory also makes predictions regarding the peak price that will be set; according to Prediction (S4), the leader of a restoration will set its price slightly above the monopoly price to maximize its profits over the course of the new cycle. While quantity data are unavailable to estimate monopoly prices in Guelph, previous empirical evidence (cited in Section 2) suggests that cycle peaks might be very predictable based on a simple markup over costs; this is not necessarily inconsistent with the Edgeworth cycle theory.[22]

Consistent with this evidence, 14 (87.5%) mode peak prices in Guelph can be simply calculated by adding 7.0 cpl and all taxes to the current London rack price, and rounding the result either to the nearest "5" or the nearest "9".[23] This predictability has important implications for both economists and competition authorities, because it suggests that when a station attempts to lead a restoration, its rivals will be less likely to confuse this restoration attempt with an alternative potential reason for a price increase, such as a station-specific gas shortage or an error on its pricing sign, thus facilitating the speed and success of the restoration.

4.1.5. The Relationship Between Retail Price Decreases and Rack Prices

The last structural prediction to be examined in this paper relates to undercutting phases. According to Prediction (S5), firms will tend to undercut one another by amounts just large enough to increase their market shares. Thus, the magnitudes of retail price decreases will tend to be relatively constant during a cycle, with the possible exception of periods toward the end of the cycle when a firm might attempt to hasten a

[22] For example, if the (hypothetical) inverse demand function is $p = A - k \ln(q)$, where A and k are demand parameters and q is quantity, and if marginal cost is c, then the monopoly price is $p^M = c + k$. In other words, the monopoly markup (k) is constant, even if A and c fluctuate over time. However, it has not been demonstrated that a firm would indeed set a constant markup over p^M, in equilibrium.

[23] With respect to the other two peaks, one is rounded down an extra 0.4 cpl to end in "5", while the other is rounded up an additional 2.0 cpl. The latter restoration coincides with a 15.2 cpl increase in the London rack price following Hurricane Katrina, and will be discussed further in Section 6.

restoration. To test this prediction, the following model will be estimated by OLS; this model is adapted from the one that Eckert (2002) estimated using average weekly retail gasoline prices in Windsor, Ontario.

$$\Delta p_t = \alpha_0 + \alpha_1 p_{t-1} + \alpha_2 r_t + \alpha_3 \Delta p_{t-1} + \alpha_4 \Delta r_{t-1} + \alpha_5 t + \beta D_t + v_t$$

where Δp_t is the change in the mean daily retail price in Guelph (excluding taxes) from Time *t-1* to Time *t*,[24] r_t is the London rack price at Time *t*, D_t is a vector of six day-of-the-week dummies (Wednesday to Monday), *t* is a linear time trend, and v_t is a random error term.[25] Since Prediction (S5) focuses on price decreases, days that are part of restoration phases are excluded from the data, leaving 69 days in the data.

With respect to the model specification, the lagged mean retail price and the current rack price are included because the magnitudes of retail price changes during an undercutting phase might depend on rack price movements and the current position of the cycle. The lagged changes in the mean retail and rack price series are included to control for the possibility that mean retail price changes might reflect recent changes in the mean retail and rack prices, other than through the current retail-rack margin; the process used to determine lag lengths is described in the Technical Appendix. The basic Edgeworth cycle theory predicts that if statistically significant, the coefficients on these variables will be estimated such that price decreases grow in absolute size as the average retail price approaches the rack price. Finally, six daily dummies (Wednesday to Monday) are added to the regression to control for potential day-of-the-week demand factors.

The results of this regression are provided in Table 3. First, the coefficients on p_{t-1} and r_t are negative and positive, respectively, and both are statistically significant at the 1% level. Also, the null hypothesis that the coefficients of p_{t-1} and r_t are equal but opposite in sign is not rejected at the 10% level of significance.

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[24] Eckert (2002) includes $log(\Delta p_t)$ as the dependent variable to ensure that price increases will not be predicted during the undercutting phase. However, the dependent variable estimated with the Guelph data is Δp_t because "step-ups" might be observed during undercutting phases; see Noel (2006), *supra* note 15.

[25] Eckert (2002) estimates the Inverse Mills Ratio (IMR) to control for sample selection bias in his data. However, restoration attempts are never observed in Guelph on weekends, so day-of-the-week effects cannot be incorporated into an estimated IMR for Guelph. On the other hand, as found in Section 4.1.3, the timing of restorations appears to be (at least partly) determined by exogenous factors, including the day of the week and prices in other cities, which could reduce any sample selection bias present in the model.

Taken together, these results suggest that the average retail price does tend to fall by larger increments the higher is the previous average retail price and the lower is the current rack price. Also, the coefficient on Δp_{t-1} is positive and statistically significant at the 10% level of significance, indicating that larger average retail price decreases in the current period are followed by even larger decreases in the next period. Finally, all six daily dummies are individually- and jointly-insignificant at the 5% level, suggesting stations do not undercut more or less aggressively on certain days of the week.[26]

A possible explanation for these results relates to findings in Section 4.1.4, which suggest that the mode monopoly margin in Guelph might be slightly below 7.0 cpl. If so, then when large daily rack price decreases occur in the data, thus raising retail-rack margins above 7.0 cpl, stations in Guelph might price more aggressively to quickly return to the monopoly price. Evidence to support this expectation is found in the Pearson correlation coefficients between the retail-rack margin and Δp_t during non-restoration days: they are -0.60 (N = 27) when the margin is above 7.0 cpl, and -0.12 for all other days (N = 42).

To examine this relationship econometrically, a dummy has been added to the original regression that equals one when the margin is strictly above 7.0 cpl and zero otherwise. Two interaction terms have also been included, which equal this dummy multiplied by either p_{t-1} or r_t. Finally, using the lag selection process described in the Technical Appendix, Δp_{t-2} and Δr_{t-2} are also included in the regression. As expected, the results of this alternative specification are consistent with the argument that the mean price in Guelph tends to fall at a relatively constant rate when the (lagged) mode retail-rack margin is below the pre-rounded peak markup of 7.0 cpl, and falls at a greater rate otherwise: no coefficients are statistically significant at the 10% level, with the exception of the coefficient for Δp_{t-2}, which is negative and significant at the 5% level.

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[26] To test whether Hurricane Katrina had a significant impact on the magnitudes of price decreases in Guelph, a dummy was added to the above regression that equals one between August 30 and September 17, inclusively; these dates were chosen because Hurricane Katrina hit the United States on August 29, and the National Hurricane Center (http://www.nhc.noaa.gov; visited 2007-10-18) issued its first advisory of Hurricane Rita on September 17, so the price effects of Katrina and Rita will not be mixed. This dummy is not statistically significant at the 10% level of significance, and the only qualitative change to Table 3 is that the coefficient of Δp_{t-1} is now significant the 5% level (p-value = 0.049).

4.2. Behavioral Predictions

4.2.1. Cycle Restorations and Firm Size

The first behavioral prediction to be considered is that large firms tend to lead price increases; in this paper, size is measured by the number of stations price controlled by each brand, and leaders are defined as the first brands and stations to increase their prices on each Day 0. However, some of these leaders raise their prices just slightly more than enough to make their retail-rack margins positive, and wait until later in the day to raise them to their cycle peaks, suggesting they might be "stepping up". Therefore, a second methodology only identifies a station as a leader if it is among the first to raise its price to its cycle peak on Day 0.

The leaders identified by these two methodologies are listed in Table 4, along with the number of times each is identified as a leader. Consistent with Prediction (B1), both methodologies tend to identify major brand stations as leaders, but they also tend to be five specific majors (Petro-Canada Stations 5, 18 and 25; and Esso Stations 19 and 26), all of which are either known or believed to be price controlled by their head offices. Notably, the only Petro-Canada station where price control is delegated to its manager (Station 14) is never identified as a leader. Finally, the three Sunoco stations are rarely identified as leaders, while no Shell Canada station is ever identified as one, despite both being Canadian refinery brands.[27]

Thus, the findings in this section go further in identifying price leaders than could have been possible using data that only include prices for a subset of stations in the market, or prices that are collected no more frequently than every 12 hours. They suggest that the size of a firm is not the only characteristic that can influence whether it is a leader of price increases, because Sunoco and Shell Canada should otherwise be

[27] One issue that arises in the identification of leaders is that, because it took 45 minutes to collect prices from all 27 stations each period, stations observed near the end of a trip are more likely to be identified as leaders than ones observed earlier in the drive. Thus, a third methodology is considered, where stations are also identified as leaders if they are observed to raise their prices to their peaks one period later than the leaders identified in the second methodology, but might have actually raised their prices first. It is found that the results using the second and third methodologies are not substantively different; no new stations are identified as leaders, while Stations 3 and 4 are each identified twice, the three Sunoco stations two to four times each, the Esso stations 10 to 12 times each, and the Petro-Canada stations 14 to 16 times each.

identified as leaders more often. The data suggest that another potential influence is the spatial location of the firm. For example, each of the other 22 stations are located within 2.2 miles of at least one of these five leaders (on a crow-flies basis), and all five leaders are also located either within one block of a mall or in the downtown core where large numbers of consumers are expected to converge. In other words, price increases initiated by these five stations might be observed by their rivals more quickly than price increases of stations where fewer consumers travel; this relative visibility might reduce the risk that a price increase will not be followed, which could increase the likelihood that a station will be willing to take this risk.

4.2.2. Price Decreases and the Aggressiveness of Independents

Next, Prediction (B2) will be considered, which is that small firms are more likely to undercut their rivals' prices than larger firms. For each period in which the city-wide minimum price falls, a station is identified as setting the minimum price in the city if it is the only station observed to set this price. Using this methodology, Table 5 lists the number of times each station is identified as setting the minimum price, excluding those that are never identified as doing so.[28] This table shows that Pioneer Station 23 sets the minimum price in 39.2% of all such cases, followed by a major brand station, Petro-Canada Station 25, which clearly sets the minimum price 15.7% of the time. The other nine independents identified in Table 1 only set the minimum price 9.8% of the time *combined*, suggesting that a higher concentration (or higher market shares) of independent stations might not necessarily lead to lower prices in a market; rather, a higher concentration of certain *types* of independents might be more likely to lead to lower prices.

In fact, the "mom-and-pop" (Group D) independent stations appear to be generally out of touch with

[28] In the data, Sunoco Stations 9 and 20 contemporaneously set their prices 0.4 cpl above the price of Sunoco Station 22 with 90.9% and 56.9% of their prices decreases, respectively, possibly reflecting a premium for full-service operations. Therefore, these two stations are considered to undercut the city-wide minimum if they price above the previous minimum price by less than 0.4 cpl. If this assumption is not made, then the only substantive change to Table 5 is that Station 20 is never observed to undercut the city-wide minimum price. Specifically, of the (now) 139 cases where a single station undercuts the entire city, Pioneer is this station 45.3% of the time; the other 25 stations's totals rise by zero to two times each.

the cycles. For example, the four Group C independent stations lower their prices an average of 120 times over the sample, while the average Group D independent station lowers its price much less frequently at 46 times, or once every 2.2 days. Furthermore, the Group D stations appear much more likely than other stations to violate the theoretical prediction that a firm raises its price to its cycle peak with a single increase. For each of the 16 restorations, while the major brand and Group C independent stations rarely, if ever reach their peaks in multiple steps, four of the Group D stations account for 56.8% of the 37 observations where a station took multiple increases to reach its cycle peak, for an average of over five times each.

Some potential reasons why Pioneer might be more price aggressive than other independent stations are as follows. First, Table 1 shows that Pioneer has at least twice as many regular-grade nozzles as each Group D station; Pioneer's pumps are also self-serve, while the pumps of the Group D stations are all full-serve. Thus, a Group D station is less able to accommodate the extra demand that it might attract by pricing aggressively. Pioneer might also have an incentive to price low so that it can attract consumers into its convenience store, where profit margins are arguably much higher than gasoline margins. On the other hand, the Group D stations operate auto repair shops instead of large convenience stores or car washes, and might consider gasoline to be a secondary business. Consistent with this explanation, Wang (2006a, 9) argues that in Perth, the small independents that do not closely follow cycles focus primarily on auto repair operations.

Pioneer might also be more likely to set the city-wide minimum price than other Group C stations because it is partly owned by a refiner (Suncor). Consistent with this explanation, Eckert and West (2004a, 41-42) argue that Sunoco and Pioneer might follow undercutting strategies in order to maximize gasoline sales and refinery utilization rates. In other words, Pioneer is unique from other Guelph independents in that it is partially vertically integrated, and so might price near marginal cost to internalize part of its double marginalization externality.

4.3. The Coordination Problem

The purpose of this subsection is to combine evidence generated in Sections 4.1 and 4.2 to explain how the coordination problem, which is expected to exist during cycle restorations, appears to be less of an issue in Guelph. First, it will be demonstrated in Section 4.3.1 that the timing and magnitudes of price increases, as well as the identities of the price leaders are quite predictable, and therefore one can recognize the initiation of a restoration relatively quickly and unambiguously. In Section 4.3.2, it will be shown that the prices of some of the first stations to raise their prices follow a specific pattern; this pattern is consistent with the explanation that in order for a firm to be willing to assume the leadership role during restorations, it would not only need to avoid the losses that would be incurred by temporarily charging the highest price in its market, but also avoid creating a reputation as a high-priced firm in that market.

4.3.1. The Predictability of Restorations

As demonstrated in Section 4.1, cycle restorations in Guelph appear to be very predictable in terms of the timing and sizes of price increases. Specifically, they are typically initiated early in the week and between noon and 2:00PM, and the mode peak price tends to be roughly predictable based on the current London rack price. These findings suggest that restoration attempts might be more likely to be successful at certain times of the week, and the peak prices set are such that they can be more easily distinguished from other reasons for posted price increases, such as a station-specific shock or an error on a station's pricing sign.

Furthermore, as argued by Noel (2006, 32-33), "The emergence of a consistent price leader ... is important for reducing these coordination problems when there are more than two firms." Such consistent leaders were identified in Section 4.2.1, where Group A stations of two specific brands were almost always identified as leaders of price increases (Petro-Canada Stations 5, 18 and 25; and Esso Stations 19 and 26). Each of these five stations typically sets the mode peak price between noon and 2:00PM on every restoration day in the data, and each is located in areas of the city where they appear relatively more likely to be quickly observed by their competitors. Thus, the predictability of these stations' price movements, as well as their

spatial characteristics suggest that consistent leaders have arisen in Guelph, and their existence might reduce the coordination problem expected during cycle restorations.

4.3.2. "Sub-cycles"

By consistently being among the first stations to raise their prices on restoration days, Petro-Canada and Esso might not only sacrifice profits to their competitors while they wait for them to raise their prices, but they could also generate a negative reputation among consumers as the high-priced brands in the city. However, it has been found that during each restoration, prices move in such a way that these risks may be reduced.

During all 16 restoration phases (and on no other days), a sub-cycle is observed where some of the first stations to raise their prices on Day 0 lower them back to (and sometimes below) their cycle troughs within two to four hours, and remain there until at least 8:00PM, after which they raise them again to their peaks. Only then do they begin to gradually lower their prices. A total of 67 sub-cycles have been observed, and while the identities of the stations are not always the same, every participant initially raises its price by 4:00PM. Three representative sub-cycles are visually displayed in Figure 5 using bi-hourly price data for Petro-Canada Station 18, where sub-cycles are observed for 13 (81.3%) restorations.

Next, Table 6 lists all brands and stations that are observed to follow this sub-cycle, along with the number of times each was observed. The five Petro-Canada and Esso stations identified as leaders in Table 4 are among the top six stations in this table. Also, nine of the 10 leaders identified in Table 4 under Methodology 2 are observed to sub-cycle at least as often as any other station in Table 6. These results suggest that leading a price increase might not be as risky as one might expect, because the first stations to raise their prices do not necessarily remain the highest-priced stations in the city during a restoration phase.[29]

[29] The Conference Board of Canada (2001, 28) argues that if a restoration attempt is not followed quickly enough, then it might be abandoned before the evening rush. Evidence found in this paper suggests that these abandonments might have actually been part of sub-cycles.

5. Alternative Theoretical Explanations of Price Cycles

The purpose of this section is to consider whether competing explanations of pricing dynamics might explain Guelph cycles more accurately than the Edgeworth cycle theory. First, oligopolistic "sticky" pricing theories cited by Borenstein, Cameron, and Gilbert (1997) predict that positive (negative) retail price changes will be triggered by positive (negative) cost changes. However, as shown in Section 4.1, the highly asymmetric cyclical patterns observed in Guelph retail prices are not observed in the London rack price.[30]

Second, it might be argued that retail price cycles are driven by demand cycles. For example, Rotemberg and Saloner (1986) and Haltiwanger and Harrington (1991) predict that firms will price counter-cyclically to prevent the breakdown of a (tacitly) collusive agreement. Thus, gasoline retailers are expected to lower their prices during high-demand periods when demand is *expected* to fall, and raise them when demand is currently low, but expected to rise in the future. However, if these theories explain the weekly cycles observed in Guelph, then demand should rise substantially at roughly the same time each week, and fall gradually as the week progresses; without quantity data, demand cannot be estimated for Guelph, but it nonetheless seems unlikely that the demand for gasoline would fall gradually as the weekend approaches. Furthermore, if Guelph is characterized by weekly demand cycles, then these theories do not explain why restoration attempts are observed less frequently than once per week when costs are falling.

A third explanation relies on inventory fluctuations. Using a monopolistically competitive, (s, S) threshold model where firms choose prices and inventory levels, Aguirregabiria (1999) predicts that prices will rise slowly until inventories are replenished and then fall rapidly, which is the reverse of the cycles observed in Guelph (and other cities where retail gasoline prices cycle). Furthermore, brand representatives contacted by e-mail reported that gasoline deliveries can occur three to four times per week and on no particular days, and that inventory deliveries can be made within a couple of hours after being ordered. Thus,

[30] While some stations might receive volume discounts off the rack price that are not received by other stations, whether or not these discounts influence retail price cycles cannot be explored because the specific contract terms for each station are not publicly available.

inventory deliveries appear to be too frequent and reliable to explain weekly price cycles.

It might instead be argued that retail gasoline price cycles arise due to intertemporal price discrimination. In other words, a retailer begins the cycle with a relatively high price that the most impatient consumers are willing to pay, and then gradually lowers its price to attract more patient consumers. For example, Conlisk, Gerstner, and Sobel (1984) predict cycles for a monopolist, but these cycles do not appear to extend to an oligopoly setting (see Sobel, 1984). On the other hand, Fershtman and Fishman (1992) predict cycles using a dynamic oligopolistic search model, but they assume that the firms sell a durable good that is purchased once by each consumer and never again, which does not apply to retail gasoline markets.[31]

Finally, a drawback of all of these explanations is that none of them make leadership predictions; they assume that firms do not observe their rivals' prices before making their own pricing decisions. This assumption not only contradicts evidence provided in this paper with respect to price leadership and the coordination problem, but also evidence identified in other retail gasoline pricing studies.

6. Price Movements Following Hurricane Katrina

Following the impact of Hurricane Katrina on the United States, retail gasoline prices in North America rose substantially, inspiring allegations of "price gouging" and calls for government intervention. Therefore, the purpose of this section is to examine price movements in Guelph during the "post-Katrina" period (defined as August 30 to September 17, 2005, inclusively)[32] to see if they are consistent with the basic Edgeworth cycle predictions, or if other theories and hypotheses might more accurately explain these price movements.

As can be seen in Figure 4, both the mode retail price and London rack price follow very similar patterns during these 19 days, as both series exhibit several large price increases between August 31 and

[31] Lewis (2005) also develops a theoretical search model to explain asymmetric price adjustment. However, he assumes that prices rise and fall in response to wholesale price movements, which does not appear to apply to retail gasoline price movements in Guelph, as demonstrated in Section 4.1.

[32] These dates were chosen to avoid mixing the price effects of Katrina and Rita; see *supra* note 26.

September 2, and then fall gradually from September 3 to 17. These similarities suggest that contrary to Prediction (S2), retail price cycles in Guelph might have been directly influenced by rack price movements.

However, the data appear to be consistent with the other seven basic Edgeworth cycle predictions, as well as with the results presented throughout this paper. The primary deviation from the results for the entire sample is found during the restoration attempt observed on August 31, where the mode retail-rack margin is 9.2 cpl. While this margin is higher than expected from the simple approximation described in Section 4.1.4, it might reflect disequilibrium behavior following the impact of Hurricane Katrina, partly due to increased uncertainty regarding future supply conditions. Consistent with this supply-side explanation, the London rack price rose another 12.0 cpl (in total) on September 1 and 2, and the mode peak price set during the subsequent restoration on September 2 is consistent with this simple cost-based approximation.

7. Conclusions

While other authors have used retail gasoline price data to test certain predictions made by the Edgeworth cycle theory, no study has been found which uses high frequency price data for all stations in a market, which is an ideal data set for such tests. Thus, the purpose of this paper was to examine several basic predictions of the Edgeworth cycle theory using prices that were directly observed at 27 stations in Guelph, Ontario, eight times per day for 103 days. In the process, an investigation was conducted into whether previous studies might have overlooked certain cycle characteristics due to data restrictions.

It was found that the data are consistent with the basic theoretical predictions regarding the basic shape of the cycle, the weak relationship between retail and rack price movements, and the strong relationship between the timing of restoration attempts and the retail-rack margin; it was also found that consistent with the theory, major brand stations tend to lead price increases while the minimum price in the city is frequently set by an independent station.

However, certain interesting pricing patterns that have not been identified in previous studies have

been identified in the Guelph data, which lead to two additional contributions to the literature. First, while one independent station (Pioneer) is observed to set the city-wide minimum price more frequently than any major brand station, this finding does not extend to independents in general, contrary to findings in previous studies. A potential explanation is that, contrary to "mom-and-pop" stations, Pioneer is more focused on gasoline sales than repair operations. Pioneer might also be more aggressive than other Group C stations due to its vertical relationship with Suncor (a refiner).

Second, the coordination problem inherent in leading price increases does not appear to be as significant a problem as one might expect. In particular, stations that are price controlled by Petro-Canada and Esso are found to be consistent leaders of price increases. These stations are located in relatively high-traffic areas, and all other stations are located within 2.2 miles of at least one of these five leaders. Also, a sub-cycle has been identified during every restoration, which appears to enable stations to lead price increases without incurring the negative consequences of raising their prices before their rivals, including temporary losses in business and reputation effects with consumers.

These results have several implications for both economists and competition authorities. First, to accurately study inter-station price dynamics in cycling cities like Guelph, prices should be collected very frequently from all stations in the market; the sub-cycles would be overlooked with data collected every 12 hours, and price leaders would be difficult to identify. Second, the source of price control and spatial proximity to areas where traffic converges, such as malls and downtown cores, appear to be important characteristics to be included in any analysis of retail gasoline price competition. Third, independent brand competition might not be as important as one might expect; rather, existing competition from certain types of independents might provide a better indication of the relative competitiveness between markets.

A final implication of the results in this paper is that while the data appear to be less consistent with other theories of pricing dynamics, certain extensions of the Edgeworth cycle theory might prove worthwhile. For example, since restorations seem to be triggered by both demand conditions and proximity to marginal

cost, a possible extension involves allowing for predictable demand fluctuations. Also, evidence regarding price leadership and the amount of time taken for stations to respond to Pioneer's price decreases imply that attention should be given to extending the theory to allow for such factors as consumer search costs and station characteristics (including spatial location, non-gasoline operations, and source of price control).

Technical Appendix[33]

Determination of Lag Lengths

A testing-down procedure is used to help determine the number of lags to be included for both the mean retail and London rack price changes. Beginning with seven lags of each series, the last lag of each one is deleted until the null hypothesis that these last lags are jointly insignificant at the 5% level of significance is rejected. This procedure chooses no lags of each variable, and a similar testing-up procedure chooses the same model. However, the Akaike information criterion (AIC) chooses two lags each, followed by one lag each as the second-best specification. Thus, a compromise between the two selection criteria is used (one lag each).

Tests for Stability

Augmented Dickey-Fuller (ADF) tests were conducted for the average retail and rack price series; the number of lags were chosen to be the largest significant lags in either the autocorrelation function or the partial autocorrelation function (seven lags for the average retail price series, and six lags for the rack price series). With a 5% critical value of -3.41, the null hypothesis of a unit root was tested against the alternative hypothesis of a deterministic trend, and the test statistics are -3.60 for the rack price series and -3.45 for the average retail price series. Thus, the null hypothesis of a unit root is rejected for both series.

Test for Autocorrelation

Popular tests for autocorrelation such as the Durbin-Watson *d* test cannot be conducted using time series data with missing observations. However, applying a Runs Test (see Gujarati, 1995, 419-20) to the regression in Table 3, for 31 runs (35 positive residuals and 34 negative residuals), the 95% confidence interval is (27.4, 43.6). Thus, the null hypothesis of random disturbances is not rejected at the 5% level of significance.

[33] The tests used in this Technical Appendix are influenced by those used by Eckert (2002) in his econometric analysis of price cycles in Windsor, Ontario.

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FIGURE 1

Examples of Theoretical Edgeworth Cycles, Assuming MC = 0 and Constant Demand

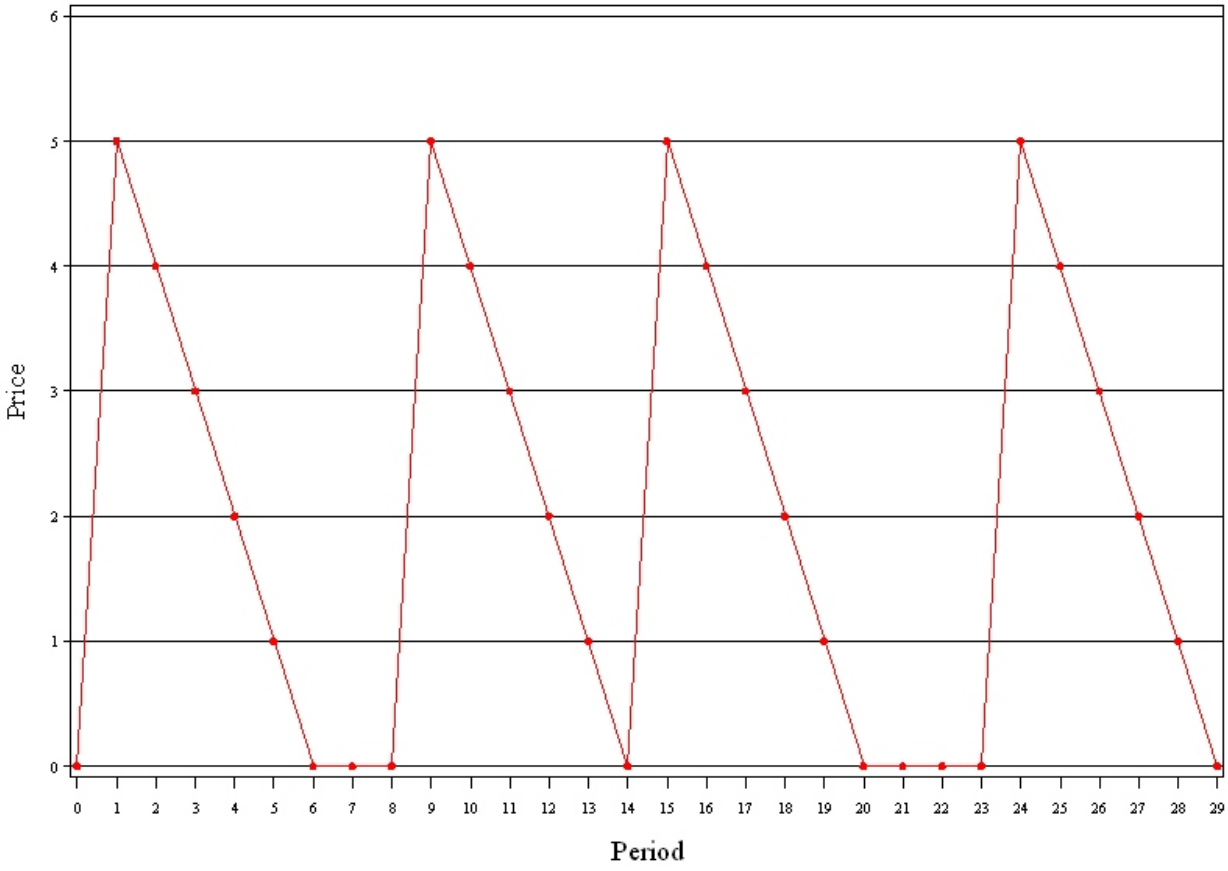


FIGURE 2

Locations of All Retail Gasoline Stations in Guelph

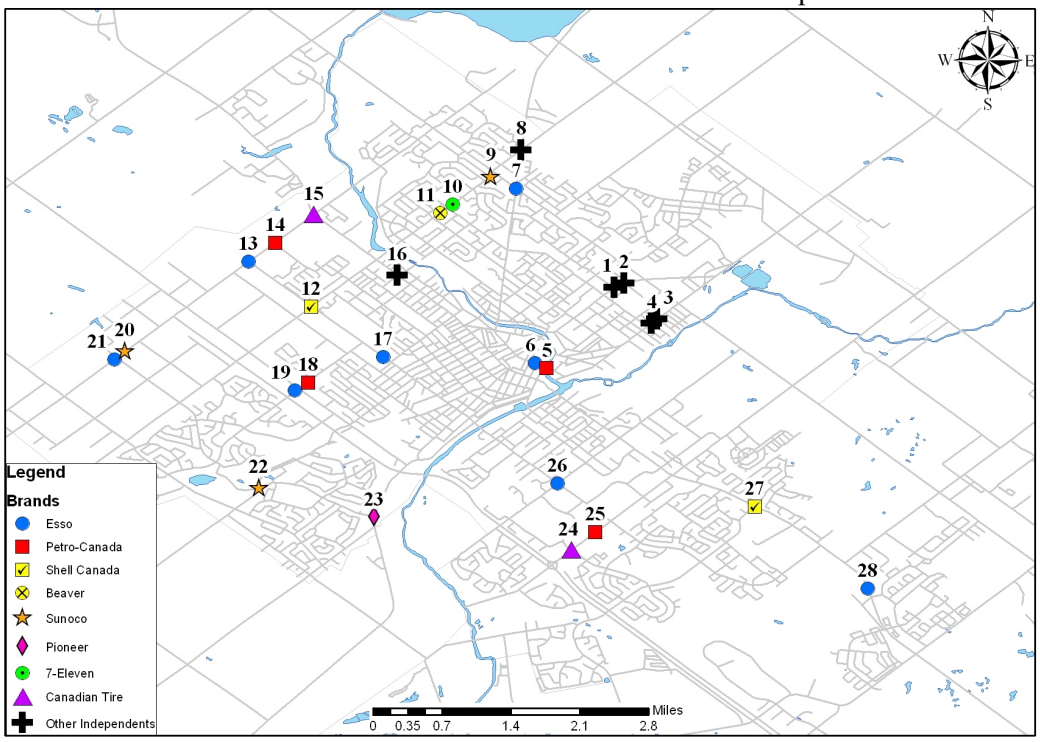


FIGURE 3

Ten Nearest Retail Gasoline Stations to Guelph

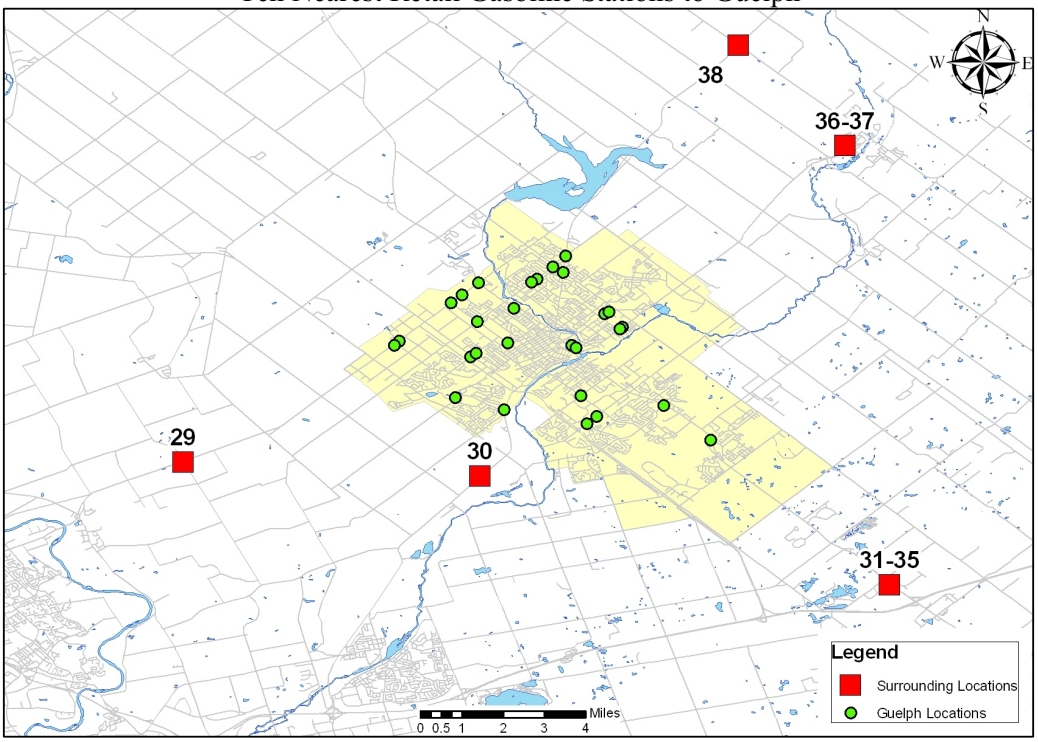
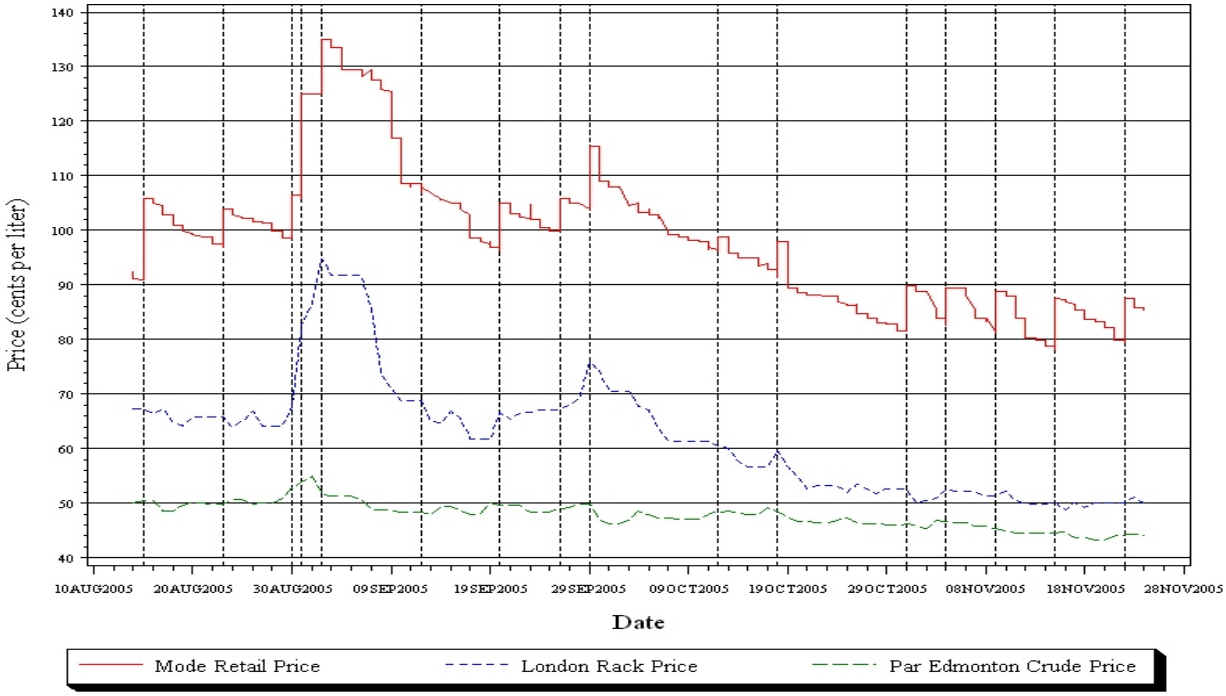


FIGURE 4

Upstream Prices and Mode Retail Price for Guelph, Ontario*



* Note: Each vertical line represents a day when a restoration was attempted.

FIGURE 5

Representative Examples of Sub-cyclical Pattern (Petro-Canada Station 18, August 14 to 30, 2005)

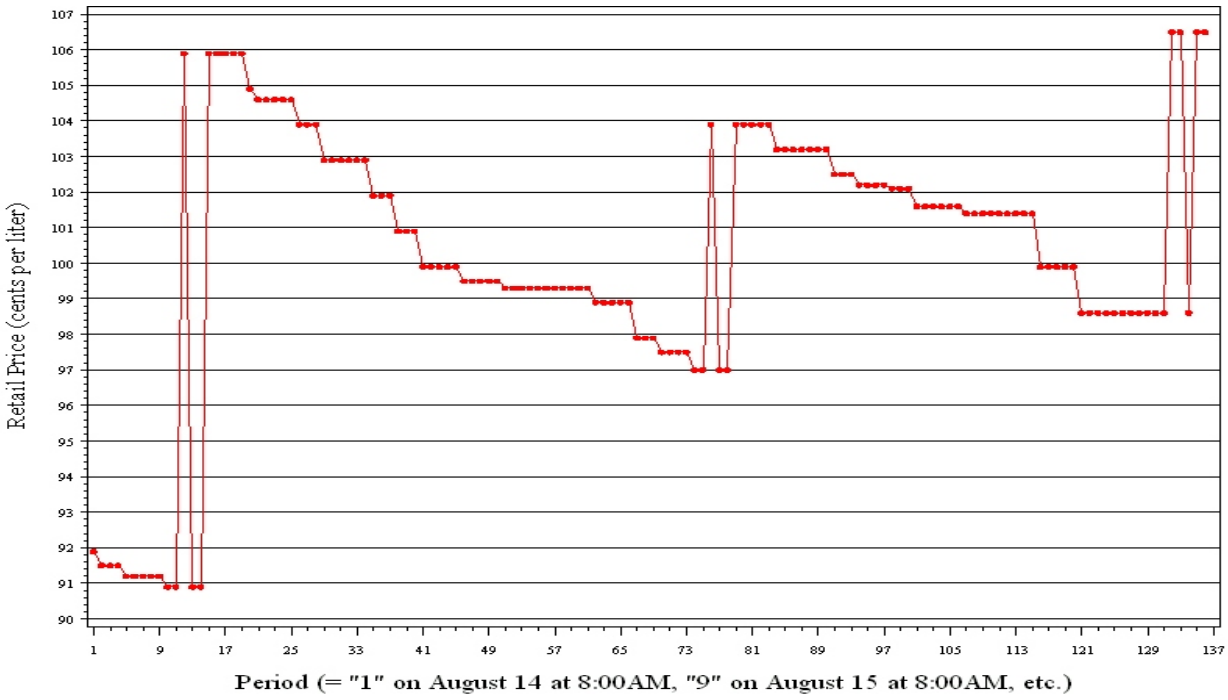


TABLE 1
Selected Station Characteristics*

Brand	ID	Nozzle Count	Open 24 Hours	Self-Serve	Store	Car Wash	Auto Repair
Group A							
Esso	19	12	✓	✓	✓	✓	
Esso	21	10	✓	✓	✓	✓	
Esso	26	8	✓	✓	✓		
Petro-Canada	5	8		✓	✓		
Petro-Canada	18	8	✓	✓	✓	✓	
Petro-Canada	25	8	✓	✓	✓	✓	
Shell	12	8	✓	✓	✓		
Shell (Mac's)	27	8	✓	✓	✓		
Shell (Beaver)	11	6					✓
Sunoco	9	6				✓	
Sunoco	20	4					
Sunoco	22	8	✓	✓	✓	✓	
Group B							
Esso (Norm's Garage)	6	4					✓
Esso (7-Eleven)	7	8	✓	✓	✓		
Esso (Gas-Up Carwash)	13	4		✓		✓	✓
Esso (Rainbow)	17	6	✓	✓	✓	✓	
Petro-Canada	14	8		✓	✓		
Group C							
7-Eleven	10	8	✓	✓	✓		
Canadian Tire	15	8		✓	✓		✓
Canadian Tire	24	6	✓	✓		✓	
Pioneer	23	8	✓	✓	✓		
Group D							
Amco	1	4					✓
Cango	2	3					✓
Hilton Group Gas	3	4					✓
Maple Leaf Gas and Fuels	4	4					✓
CAN-OP	8	2					✓
Quik-N E-Zee Gas & Snacks	16	2					✓

* Petro-Canada Station 18 is the only station with both full- and self-serve pumps; since the self-serve price is observed, only those pumps are counted. Also, a "store" is a convenience store, except for Canadian Tire Station 15 where it is a Canadian Tire department store.

TABLE 2
Summary Statistics

Station-Specific Bi-Hourly Price Data	
Average price increase	7.3 cpl
Average price decrease	1.4 cpl
Average number of price increases per station	21
Average number of price decreases per station	116
City-Level Daily Price Data*	
Average increase in city-wide mean price	3.8 cpl
Average decrease in city-wide mean price	1.3 cpl
Average increase in city-wide mode price	7.7 cpl
Average decrease in city-wide mode price	1.9 cpl
Number of mean price increases	25
Number of mean price decreases	77
Number of mode price increases	16
Number of mode price decreases	68
Average duration of an undercutting phase	5.0 days
Average duration of a restoration phase	1.2 days
Average total cycle duration	6.2 days
Daily London Rack Price Data	
Average increase	2.4 cpl
Average decrease	2.1 cpl
Number of increases	28
Number of decreases	39

* The mean price rises more frequently and by smaller amounts than the mode price, because it typically takes two days for all stations in the city to raise their prices during restorations.

TABLE 3

OLS Regression Results (Dependent Variable: Δp_t)

Variable	Coefficient		t-ratio	Hypothesis Tests
p_{t-1}	-0.23856	*	-5.13	
r_t	0.23948	*	4.29	
Δp_{t-1}	0.11619	***	1.96	*F-stat for joint significance of day-of-week*
Δr_{t-1}	-0.11843		-1.45	*dummies*
$SUNDAY_t$	-0.36504		-0.71	0.70 with 6 and 57 df (p-value = 0.651)
$MONDAY_t$	-0.57471		-1.08	
$WEDNESDAY_t$	-0.19082		-0.30	*F-stat for* H_0: $p_{t-1} + r_t = 0$
$THURSDAY_t$	-0.11625		-0.20	0.00 with 1 and 57 df (p-value = 0.965)
$FRIDAY_t$	-0.31885		-0.57	
$SATURDAY_t$	-0.83357		-1.55	N = 69 Adjusted R^2 = 0.37
t	-0.00572		-0.82	
CONSTANT	0.95046		0.57	

* Statistically significant at the 1% level of significance (two-tail).

*** Statistically significant at the 10% level of significance (two-tail).

TABLE 4

Number of Times Each Station Is Identified as a Leader of a Restoration (Out of 16 Restorations)*

Brand	ID	Group	Count (Methodology 1)	Count (Methodology 2)
Petro-Canada	25	A	11	15
Petro-Canada	5	A	8	12
Petro-Canada	18	A	7	11
Esso	19	A	8	10
Esso	26	A	6	9
Sunoco	22	A	1	2
Sunoco	9	A	2	1
Sunoco	20	A	0	1
Hilton Group Gas	3	D	2	1
Maple Leaf Gas and Fuels	4	D	0	1
Quik-N E-Zee Gas & Snacks	16	D	2	0

* See Section 4.2.1 for definitions of each methodology. More than one station is usually observed to raise its price in a single period, so the total counts do not add to 16. Also, only stations identified as leading a restoration at least once using either methodology are included in this table.

TABLE 5
Number of Times Each Station Is Observed to Set the City-wide Minimum Price (N = 153)*

Brand	Station ID	Group	Count	Proportion
Pioneer	23	C	60	39.2%
Petro-Canada	25	A	24	15.7%
Sunoco	20	A	23	15.0%
Esso (Rainbow)	17	B	11	7.2%
7-Eleven	10	C	6	3.9%
Hilton Group Gas	3	D	5	3.3%
Petro-Canada	14	B	5	3.3%
Shell (Mac's)	27	A	5	3.3%
Esso (7-Eleven)	7	B	3	2.0%
Esso	26	A	3	2.0%
Petro-Canada	5	A	2	1.3%
Quik-N E-Zee Gas & Snacks	16	D	2	1.3%
Petro-Canada	18	A	2	1.3%
Maple Leaf Gas and Fuels	4	D	1	0.7%
Canadian Tire	24	C	1	0.7%

* Only stations observed to solely set the city-wide minimum price at least once are included in this table. Also, Sunoco Stations 9 and 20 are considered to have undercut all other Guelph stations if their prices are strictly less than 0.4 cpl above the previous minimum price (see footnote 28).

TABLE 6
Number of Times Each Station Is Observed to Sub-cycle (Out of 16 Restorations)*

Brand	Station ID	Group	Count
Esso	19	A	14
Petro-Canada	18	A	13
Petro-Canada	5	A	11
Hilton Group Gas	3	D	5
Maple Leaf Gas and Fuels	4	D	4
Sunoco	9	A	4
Petro-Canada	25	A	4
Esso	26	A	4
Esso (Rainbow)	17	B	2
Sunoco	22	A	2
Shell	12	A	1
Esso	21	A	1
Pioneer	23	C	1
Canadian Tire	24	C	1

* Only stations identified as sub-cycling at least once are included in this table.