A more recent version of this article has been accepted for publication in:
Energy Economics, 2012

Edgeworth Price Cycles and Intertemporal Price Discrimination

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May 10, 2011

Abstract

In a retail gasoline market exhibiting Edgeworth Price Cycles, prices change asymmetrically with many small decreases interrupted by occasional large increases. The result is a *de facto* menu of prices from which consumers can choose based on exactly *when* they buy. This article introduces four classes of purchase timing strategies designed to systematically shift consumer purchases towards the cycle troughs. It shows in the study market of Toronto, Canada, the monetary gains to consumers from optimized timing strategies are as high as 3.9%. Markups earned from these consumers fall up to 82%. In spite of the gains from timing strategies, surprisingly few consumers use them. Evidence is presented that a main reason is that consumers are not well informed about the cycles. Policy implications are discussed.

JEL Classification L13, L41, L81

> *"If drivers can pump gas at a lower price and they get that advanced notice, believe me they're going appreciate that so they can at least co-ordinate their consumer spending habits" - MPP Joe Tascona, 2007, when introducing a bill in the Canadian House of Commons that would require gasoline companies to give consumers 72 hour advance notice of gasoline price increases.*

1 Introduction

In retail gasoline markets that exhibit a pricing phenomenon known as Edgeworth Price Cycles, consumers have the option to buy at a relatively high price or a relatively low one depending on exactly *when* they buy. Edgeworth Price Cycles are a competitive pricing phenomenon in which prices cycle asymmetrically at a high frequency. They were formalized theoretically by Maskin & Tirole (1988) and studied empirically in retail gasoline markets by many authors (Noel (2007a), Noel (2007b), Noel (2009), Eckert (2002), Eckert (2003), Eckert & West (2004), and Atkinson (2009) in Canada, Lewis (2009), Lewis & Noel (2011) and Doyle et al. (2008) in the U.S., Wang (2009a) and Wang (2009b) in Australia, Foros & Steen (2008) in Norway, and others). The bulk of the literature supports the argument that the price process is that of Edgeworth Price Cycles. The view is further supported by various government reports and by recent direct testimony from gasoline company executives (Conference Board of Canada (2001), Australian Competition Commission (2007)).

Figure 1 shows the retail price series for the twenty-two gasoline stations in the city of Toronto, Canada used in this study. The twelve-hourly data, spanning four months in 2001, shows the asymmetric pattern clearly. A cycle begins when firms repeatedly undercut one another's price to steal market share back and forth. For goods like gasoline that are close to homogeneous with high cross price elasticities, it pays to do this. Gradually price falls toward marginal cost and margins approach zero. In the study market, the process usually lasts about a week. Then with prices at or near cost, one of the firms relieves the price pressure by increasing price at its stations by a significant amount, as much as 15% here. Others follow quickly with similar price increases and then, from the top of the cycle, a new wave of price undercutting begins. The result is an asymmetric price cycle with many small price decreases interrupted by occasional, large price restorations, and it repeats over and over.

The figure suggests that intertemporal changes in retail gasoline prices can be large and even predictable when there are Edgeworth Price Cycles. Although not an effort by firms to intertemporally price discriminate, the net effect of the cycles is that consumers have the ability to systematically purchase at a relatively high or a low price depending on *when* they buy.[1] Price elastic consumers can in principle use the predictability to their advantage and

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[1] Models of intertemporal search can themselves generate an asymmetric cycle similar to these (e.g. Conlisk et al. (1984), Fershtman & Fishman (1992)), as discussed later. These models rely on complete information and foresight by consumers.

increase their surplus.

It would seem a desirable strategy for many. High gasoline prices have long proven to be a contentious issue in the study market and in many others. In Toronto, claims of "collusive" pricing and "price-gouging" voiced by consumers and even some politicians are popular topics in the press. Consumer complaints in several countries have spawned large scale investigations to test such claims.[2] Complaints in some markets have led to the passage of price regulation in the form of divorcement, below-cost-selling, or anti-price-gouging laws. Although these investigations routinely find no evidence of widespread illegal practices and in spite of the fact that regulatory responses are often of dubious merit, the source of political pressure is clear. Many consumers feel they pay too much for gasoline and want to pay less. And if that is true, predicting when the troughs will occur in Edgeworth Price Cycles markets presents one way to pay less. But surprisingly, the evidence shows that few consumers in the study market used any kind of purchase timing strategy at all that would predict when low prices would occur.

How large are the potential gains from timing purchases? The primary goal of this article is to promote the use of purchase timing strategies designed to move purchases systematically closer to the troughs and reduce the average price paid by strategy followers. I show the gains can be significant for interested consumers.

I proceed in several stages. First, I estimate a series of regressions to identify a set of four triggers that can potentially predict when the large price increases are coming. Then I introduce and design four general classes of purchase timing strategies based on these triggers. The strategies must not only be effective but simple to follow as well. Third, I generate a consumer purchase profile for a number of possible timing strategies within each class by using variants of the purchase trigger rule for that class. For each purchase profile, I calculate the average price paid by consumers and the average markup received by firms

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[2] While there have been isolated cases of price fixing by individual station dealers in local markets (eg. Ballarat, Australia (Wang (2008)) or four nearby towns in Quebec, Canada (Clark & Houde (2009), comprehensive investigations in various countries have found no evidence in support of collusion or price fixing amongst the large gasoline companies.

from consumers using that strategy. Then I select from each class of strategies the single optimized strategy that maximizes the gain from the class. Finally, I compare the optimized purchase timing strategies across classes and to no timing strategy at all, to arrive at the best techniques for predicting cycle troughs and lowering the average price paid. I show that monetary gains of up to about 4% were readily available in the study market from using purchase timing strategies relative to purchasing myopically. Gains of 2.3% were available with arguably very little effort. The reduction in firm markups from such consumers are very large: 82% and 45% respectively.

The magnitude of the monetary gains are especially significant in light of the maximum possible gains from traditional contemporaneous search. They are at least *twice* as great and as much as *four times* as great as those obtainable from searching and buying at the cheapest of a handful of local stations in the area. They are even greater than the gains that could be had from checking prices at all twenty-two stations in the sample spread out across a seventeen mile distance and buying from the cheapest of those. I argue the relative search advantage of time versus space comes from the fact that Edgeworth Price Cycles create significant (and predictable) variation in prices over time while simultaneously compressing the price distribution across stations at a given point in time. Consumers are well known to be price elastic in the study market in a contemporaneous sense (which contributes to cycle generation in the first place), making the available potential gains from intertemporal switching all the more significant.[3]

I conclude that Edgeworth Cycles provide a mechanism by which price elastic consumers can pay significantly and systematically below the market average price using optimized timing strategies.

There are three caveats to this result to keep in mind. First, the gains are calculated at the margin. If timing strategies were to come into extensive use, then firms can be expected to adapt in response to the demand changes, and it is conceivable the existence of the cycle

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[3] Noel (2008) shows high firm level elasticities are needed for cycle generation.

itself might be affected. I appeal to the Australian experience, however, to argue that even with extensive use, the cycle is likely to continue. Of course, the timing strategies introduced here would likely need to be reoptimized as demand patterns change.

The second caveat is that the timing strategies here were optimized specifically for the study market of Toronto for 2001. The general classes of timing strategies are portable across markets, but each strategy class must be optimized for each market separately and then reoptimized time to time as conditions change. Certain ones may work best in one market, others in a different one, noting that even small departures from the optimized setting can evaporate monetary gains quickly.

The third caveat is that there are non-monetary costs associated with using purchase timing strategies, often in the form of time and effort spent. These costs can be significant and overwhelm the monetary gains from using a timing strategy. Indeed, few consumers in the study market appear to use a timing strategy at all and non-monetary costs are a likely cause.

It is worth exploring whether the non-monetary costs of implementing timing strategies or a basic lack of awareness of the cycle is responsible for the absence of timing strategy use. I report evidence from several sources suggesting that cycle awareness in the study market was very weak. Back of the envelope calculations suggest that the non-monetary costs under certain timing strategies are unlikely to be high for a marginal consumer. The implication is that, at the margin, sizeable welfare gains were being left on the table by at least some consumers poorly informed about the cycles and how to time them, rather than by the magnitude of non-monetary costs alone.

There are policy implications. In an environment where consumers are highly price elastic and openly wary about high gas prices, welfare gains can be achieved by making consumers more aware of the cycle. This should be done. Especially given the sometimes hostile tone of the dialogue, the effort to inform consumers about the cycle has been weak. This is in striking contrast to the Australian experience, where a public information campaign about the cycles has been strong and a large proportion of consumers try to time their purchases to periods of low prices. For markets with Edgeworth Cycles where consumers are not as well informed, this paper provides an independent contribution. It illustrates the predictable nature of the cycles and introduces four classes of purchase timing strategies - portable across markets - to show how one can exploit the predictability in the cycle, time the troughs, and lower the average price paid to the benefit of price elastic consumers.

2 Strategy Search

The study market is Toronto, Canada, which experiences strong retail price cycles, as seen in Figure 1. I use a dataset of twelve-hourly retail prices for twenty-two service stations along an assortment of major city routes on a grid in central and eastern Toronto over 131 consecutive days between February 12^{th} and June 22^{nd}, 2001. The stations are a representative mix of large major national and regional firms and smaller independent firms. Thirteen of the stations surveyed are operated by major national or regional firms and nine by independents. Twelve firms are represented in total including all major national and regional firms. Retail prices, $RETAIL_{st}$, are for regular unleaded, 87 octane, self-serve gasoline, in Canadian cents per liter (cpl). The wholesale price I use is the daily spot rack price for the largest wholesaler at the Toronto rack point, $RACK_{st}$, and is the best available measure of the wholesale price.[4]

The first steps are to estimate the underlying cycle process and test for the potential triggers that indicate when the next large price increase is about to occur.

Edgeworth Cycles are characterized by many periods of small price decreases at a given station interrupted by a single period with a large price increase. When a station raises its price, I say it is in its relenting phase (phase "R"). The rest of the time prices at a station decrease or occasionally remain unchanged from one period to the next twelve hours later. I call this the undercutting phase (phase "U"). The separation of phases in the data

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[4] Branded stations and many large independent stations purchase at prices specified in confidential supply contracts.

is very clear, as seen in Figure 1, and allows an easy categorization and estimation of each component of the cycle separately.

Let I_{st} equal R or U when in a relenting or undercutting phase respectively. I assume the probability that a station s at time t switches from an undercutting phase to a relenting phase is given by the probit specification:

$$\begin{aligned} \lambda_{st}^{UR} &= \Pr(I_{st} = R \mid I_{s,t-1} = U) && (1) \\ &= \Phi[\theta_0^U + \theta_1^U PT_{st} + \theta_2^U BTYPE_s + \theta_3^U M_{st}] && (2) \end{aligned}$$

where PT is a set of potential triggers for predicting the switch. $BTYPE$ is a station type dummy (equal to 1 for stations operated by major integrated firms, 0 for independents) and M is a set of calendar month dummies. As seen in Figure 1 and reported below, when a price increase occurs, it is large, so predicting when this switch is about to occur is the critical element in designing a successful timing strategy.

The probability of "switching" from an undercutting phase in one period to another undercutting phase the next period is given by $\lambda_{st}^{UU} = 1 - \lambda_{st}^{UR}$. Since two consecutive relenting phases are extremely rare in the data, there is no meaningful variation to explain and the switching probability $\lambda_{st}^{RR} = 1 - \lambda_{st}^{RU}$ is assumed to be an estimable constant.

Define $\Delta RETAIL_{st} = RETAIL_{st} - RETAIL_{s,t-1}$. I assume if station s chooses to change price at time t while in phase i, it does so according to the function

$$\alpha_{st}^i = \beta_0^i + \beta_1^i PT_{st} + \beta_2^i BTYPE_{st} + \beta_3^i M_{st} + \varepsilon_{st}^i \qquad (3)$$

where $\alpha_{st}^i = (\Delta RETAIL_{st} \mid I_{st} = i, \Delta RETAIL_{st} \neq 0)$, $\varepsilon_{st}^i \,\tilde{}\, N(0, \sigma_i^2)$ and PT_{st} is again the set of potential triggers.[5]

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[5] Although price increases and decreases are separately analyzed, these are not censored regressions. Positive and negative price changes are generated by separate processes and observations drawn from their complete distributions are observed.

There are no zero price changes in relenting phases which virtually always last one period, but there are during undercutting phases given the high frequency of the data. Let J_{st}^U be the indicator function equal to 1 when a station s is in an undercutting phase but its price does not change. The probability $J_{st}^U = 1$ is given by the probit specification:

$$\begin{aligned}\gamma_{st}^U &= \Pr(J_{st}^i = 1 \mid I_{st} = U) && (4)\\ &= \Phi[\zeta_0^i + \zeta_1^i PT + \zeta_2^i BTYPE_s + \zeta_3^i M_{st}] && (5)\end{aligned}$$

This completes the model.

Now consider the potential triggers. Figure 1 suggests four triggers that can be helpful in predicting when the next peak is imminent. First, notice the trough of each cycle in the figure appears close to the wholesale price. Define $POSITION_{st}$ as the difference between the lagged retail price and the lagged rack price, less taxes, $RETAIL_{s,t-1} - RACK_{s,t-1} - TAX_{s,t-1}$. This is a measure of the position of a station's tax exclusive price relative to the bottom of its cycle. Noel (2007a) and Noel (2007b) show that when $POSITION$ falls, the probability that a station will switch from undercutting to relenting should increase. $POSITION$ is a potentially useful predictor of the next peak.

Second, Figure 1 suggests the period of the cycle (time between troughs) is correlated from one cycle to the next. This suggests that if a price increase has recently occurred, there will not be another one too soon thereafter. Define $RELENTED5_{st}$ as the dummy variable equal to one if station s has increased price at any time in the previous 5 days.[6] I expect the probability of a price increase to rise when $RELENTED5$ turns off.

Third, the price increases in Figure 1 are more concentrated from Mondays to Thursdays and are less common on Fridays or weekends. This suggests that the day of the week itself can be a simple and predictive trigger. Define D_{st}^d as the complete set of dummy variables, one for each day-of-the-week d.

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[6] Using other lengths gives expected differences in results. Recall that strategies will be optimized later.

Finally, Figure 1 shows that when some stations increase price, others are very quick to follow. Define $FOLLOW_{st}$ to be equal to one in period t if some other station has already relented as of the previous period but station s has not. Since all stations relent each time and relenting rounds are well separated, this variable is easily constructed. Noel (2007b) previously showed that $FOLLOW$ was a strong predictor of the probability of switching from undercutting to relenting.

Let $PT_{st} = \{POSITION_{st},\ RELENTED5_{st},\ D^2_{st}...D^7_{st},\ FOLLOW_{st}\}$, with D^1_{st} as the omitted Monday dummy. In the main specification (Specification (3)), I test whether these triggers are have predictive value for the next relenting phase price increase. Although predicting the λ^{UR} well is the key, I include PT_{st} in all other equations (i.e. $\alpha^R, \alpha^U, \gamma^U$) as well since triggers may also predict the magnitude of price changes when they do occur.

Table 1 reports summary statistics of the data. Tables 2 and 3 report results from two preliminary and simplified specifications (Specifications (1) and (2)) of the four equation model above that do not include triggers. The purpose of the preliminary specifications is to estimate the mean characteristics of the cycle, such as period, amplitude and asymmetry.[7]

Specification (1) excludes all right hand side variables except constant terms and yields overall mean estimates of the α^i, λ^{ij}, and γ^U. The results are reported in the first column of Table 2. They show the mean average price increase in a relenting phase is 5.56 cpl (α^R). The mean price change in an undercutting phase, conditional on a non-zero change, is -0.75 cpl (α^U). The mean probability that the price does not change from one period to the next twelve hours later is 0.43 (γ^U). The probability of two consecutive relenting phases is extremely small ($\lambda^{RR} = 0.007$) but the probability that an undercutting phase continues an extra period is very high ($\lambda^{UU} = 0.92$).

Noel (2007b) shows how to derive estimates of period, amplitude and asymmetry from these estimates. The first column of Table 3 reports results. The mean duration of the relenting phase is 1.007 periods and the mean duration of the undercutting phase is 12.73

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[7] These two specifications are similar to that in Noel (2007b).

periods, for a mean cycle period of 13.74 periods (about a week). The mean cycle asymmetry (duration of the undercutting phase divided by the duration of the relenting phase) is 12.73. The mean amplitude is 5.6 cpl.

Specification (2) repeats Specification (1) except that it includes $BTYPE$ in all equations to yield separate mean estimates for majors and independents. The results in the second column of Table 2 show the only notable difference between majors and independents is that the expected price change in a relenting phase is higher for majors and, in absolute value, the expected price change in an undercutting phase is also higher. This translates into a greater average amplitude for major firms (5.83 cpl) than for independents (5.27 cpl) in the second column of Table 3. Durations, period, and asymmetry are insignificantly different between the two.

The preliminary specifications confirm the visual takeaway from Figure 1. Cycles are about a week long, they are highly asymmetric, and there is a significant difference in price from the top to the bottom. The latter is what creates the opportunity of significant monetary gains from purchase timing strategies.

Specification (3) in Table 4 contains the full model that includes triggers. There is a separate regression for each equation (Columns (3a) - (3d)). The most meaningful results are in Column (3a), where λ^{UR} is the dependent variable (the probability of switching from undercutting to relenting).

The results show that all four proposed triggers are significantly correlated with the λ^{UR}. They have predictive power. As $POSITION$ falls by one towards zero, there is a statistically significant 4.1% increase in the probability of a new relenting phase price increase (i.e. λ^{UR} rises). The coefficient on $RELENTED5$ shows a price increase is significantly less likely to occur within 5 days of the previous price increase. Also, the day of the week carries some predictive power. Mid-week is the most likely window for new relenting phases while Friday and weekends are significantly less likely.[8] Finally, when some other station has

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[8] The regressions in Columns (3a) and (3b) drop Sunday observations since no price increases were observed in the data on those days.

already relented in the current week, so that $FOLLOW$ switches on, there is a strong 73% increase in the probability that a given station will increase price within the next 12 hours. The $MAJOR$ coefficient shows that, all else equal, a major firm is more likely than an independent to relent first.

Each of the four triggers in PT have potential value in predicting the peaks. Each will form the basis for a different class of purchase timing strategies developed and optimized in the next section.

Columns (3b)-(3d) complete the model. They show that the triggers can also predict price changes in the relenting phase (3b) and in the undercutting phase (3c) and also the probability of zero price change periods (3d).

The results of column (3b) show that lower $POSITION$ is associated with a greater price increase during the relenting phase. It is almost one for one showing that firms are reestablishing a roughly constant markup at each cycle peak. The $RELENTED5$ coefficient shows that relenting phase price increases are greater if firms last relented within the previous five days.[9] The coefficient on $FOLLOW$ shows that following stations increase prices by a bit less than leading stations do, although the effect is statistically insignificant. The coefficient on $MAJOR$ implies major firms increase prices the most.

The results of column (3c) show that undercuts are slightly smaller in absolute value when $POSITION$ is low (at the cycle bottom) and undercuts are slightly smaller if firms more recently relented ($RELENTED5 = 1$). Undercuts are larger midweek and smaller over the weekends, and larger in absolute value for major firms. Following firms ($FOLLOW = 1$), if they undercut, do so by a smaller amount in absolute value.

Finally, column (3d) shows that the probability of non-zero price changes does not significantly change on average as $POSITION$ changes or if firms recently relented ($RELENTED5 = 1$). Following firms ($FOLLOW = 1$) are significantly more likely to hold prices steady, and zero price changes are most common mid week. Independents hold prices steady more fre-

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[9] When wholesale prices are expected to rise, cycle periods are shorter and relenting phase price increases are higher, as seen in Figure 1.

quently than majors.

I now design strategies based on these triggers for practical use.

3 Strategy Design

The results of the preceding section suggest four classes of purchase timing strategies. I call them 1. Position Based Strategies, 2. Spike and Wait Strategies, 3. Calendar Based Strategies, and 4. the Spike and Buy Strategy. The alternative to timing strategies are Myopic Strategies which do not attempt to time purchases.

Myopic Strategies

Myopic strategies use no information about the cycle or past prices and make no predictions of future prices. Under the *Basic Myopic Strategy*, the consumer purchases gasoline as needed, perhaps when her fuel gauge falls below a comfortable level.[10] This is the benchmark. I abstract away from contemporaneous switching issues by assuming the consumer always purchases from her preferred station under this strategy.[11]

The *No-Queue Myopic Strategy* is a refinement that allows her to avoid any significant queueing at her preferred station. If there is a significant queue at her preferred station, she purchases at a nearby station with no queue. This refinement is motivated by the empirical observation that significant queues can form at certain stations at certain times. I will discuss more fully below, but it is a consequence of a distinct group of consumers following the Spike and Buy purchase timing strategy who concentrate their purchases according to that strategy and create abnormally large queues at particular times.

Other variations are possible. The *Major-Preferred Myopic Strategy* is a refinement in which she purchases from her preferred station assuming that station is operated by a major brand. The *Independent-Preferred Myopic Strategy* assumes the preferred station

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[10] She may also purchase on a schedule related to other considerations but not to expectations of price.

[11] I allow for both types of switching later. Also, I assume also consumers are uniformly distributed across stations, so the average price paid is a simple average of the prices paid across stations.

is an independent.

Position Based Strategies

All remaining strategies are timing strategies. The first class is the class of Position Based strategies. Table 4 showed the probability of the next relenting phase price rises as *POSITION* falls. Under a Position Based strategy, the consumer must check the rack price and the retail price and calculate the current position of the cycle. Rack prices are available online.

Under the *Threshold-Equal-Y Position Based Strategy*, the consumer purchases as soon as the difference between the tax exclusive retail price and the rack price reaches a given threshold Y.[12] The value Y can be optimized to minimize the average price paid. If Y is too high, monetary gains are foregone. If too low, the consumer might miss the trough altogether and have to purchase again near the next peak. If missed, I conservatively assume the consumer must buy right at the peak.

Buying at the peak may be a harsh penalty, but the consumer cannot wait indefinitely for the threshold to be reached if Y is set unrealistically low. A refinement of the strategy is the *Threshold-Equal-Y with Delay Position Based Strategy*. Under this refinement, if the consumer misses a trough, she has up to 10 days from her last purchase to purchase fuel again. The value 10 is chosen as the approximate time between fillups for the average driver, calculated using data from Transport Canada (2005) and discussed later. The With Delay refinement allows the consumer (typically) a few extra days for the price to fall a bit from its peak level before she buys (although it will typically be still well above the trough price).

The *No-Queue Threshold-Equal-Y Position Based Strategy* is a refinement under which she purchases at a nearby random station with no queue if her preferred station suffers a queue.

This and other classes of timing strategies are not without cost. Because Position Based strategies involve finding and looking up rack prices, it is one of the most effort intensive. I

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[12] Consumers who purchase less frequently can skip troughs as needed.

return to non-monetary cost considerations later.

Spike and Wait Strategies

The class of Spike and Wait Strategies calls for purchasing gasoline a fixed number of days after the last observed price increase. These strategies require less effort than Position Based strategies, and are potentially valuable given the significantly negative coefficient on $RELENT5$ in Column 1 of Table 4.

The strategy takes advantage of serial correlation in the cycle period (i.e. number of days between peaks).Under this strategy, the consumer notes the time the price went up at her preferred station and then purchases X days after the increase.[13] I call this the *X-Day Spike and Wait Strategy*, where X is the number of days since the last price spike, to the nearest half day.

The value of X can be optimized. If X is too small, she purchases too close to the previous peak. If too large, she can miss the trough and be required to purchase when prices are high and close to the next peak. The *No-Queue Spike and Wait Strategy* is a refinement under which she purchases at a nearby random station with no queue if her preferred station suffers a significant queue.

If she misses the trough and prices return to their peak, the consumer would benefit from delaying her purchase a few days later once prices have fallen a bit. The *X-Day With Delay Spike and Wait Strategy* is a refinement that allows the consumer to wait up to 10 days from her last purchase if she misses the trough while waiting for the X^{th} day.

Spike and Wait strategies remain feasible when the consumer does not observe prices every day. If an observation is missed but the price has not increased by the next observation, no information is lost. If it did increase, she assigns an equal probability that the price increased on the missed day or the current day. Then she waits X - 1/2 days to purchase under risk neutrality.

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[13] If she needs to purchase less frequently, she could purchase X days after every other price increase, every third, or so on.

Calendar Based Strategies

If there is serial correlation in the cycle period and if relenting phases also tend to recur regularly at times on the clock or days on the calendar, the class of Calendar Based Strategies can be very effective. They are especially simple and once set up require no information collecting at all. In Norway, for example, relenting phases tend to occur on Mondays (Foros & Steen (2008)) and in Australia on Wednesdays or Thursdays (ACCC (2009)).[14]

While relenting phases do not occur on the same day of the week every week in the sample market of Toronto, the day-of-the-week dummies in Column 1 of Table 4 show that relenting phases were less common over the weekends. This regularity is exploitable. The *Z Calendar Based Strategy* calls for the consumer to purchase at a specified recurring time Z, where Z is a half-day in the data (A.M. or P.M. of a given day during the week). The value of Z can be optimized.

The *No-Queue Z Calendar Based Strategy* is a refinement under which she purchases at a nearby random station with no queue if her preferred station suffers a queue at the designated time of purchase. The *Z With Delay Calendar Based Strategy* refinement allows her to delay up to 10 days from her last purchase if she misses the weekly trough when prices jump up just prior to her chosen day and time Z.

Both Calendar Based strategies and Spike and Wait strategies are effective when cycle periods are regular. A Position Based strategy would be a better predictor when the period is irregular, longer, or when wholesale prices are more volatile.

Spike and Buy Strategy

The Spike and Buy strategy is effective for timing the precise bottom of the cycle. The consumer observes prices at a small subset of stations each day. When she observes a large price difference between any two stations, she immediately buys from her preferred station if it is still a low priced station or a nearby low-priced one otherwise. The coefficient on the

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[14] Reasons why cycles may line up with calendar events include firms wanting higher prices during periods when demand is higher (Noel (2007b)) or firms being better able to successfully lead relenting phases when other firms anticipate their timing better (Foros & Steen (2008)).

trigger *FOLLOW* in the first column of Table 4 was large and significantly positive, showing that price increases by some stations in the last period is a strong predictor of more price increases in this period.

Unlike some other purchase timing strategies, the design of the Spike and Buy Strategy does not require an awareness of the cycle and needs no memory of past prices. The consumer needs only recognize that when a few stations significantly raise price for whatever the perceived reason (cost increases, demand changes, long weekends, cycles, collusion, etc.), it is a signal that others will raise prices soon after.[15]

As discussed later, this strategy is in some use. The result is that purchases by followers of Spike and Buy are concentrated in a short window of time at select stations whose prices have yet to rise. Long queues form quickly at peak times at the still low priced stations and often spill out on to the street.[16] I assume queueing is not relevant outside this window at these stations.[17] Waiting in queues comes at a cost. While No Queue refinements of other strategies are available, almost all followers of this strategy (all but the first movers) must queue and there is no No-Queue version of it. The requisite queueing also suggests another observable trigger - just look for the queues. Finally, I assume followers of this strategy observe the trigger each week so there is no With Delay version.

Other Strategies

Other strategies are possible, including hybrid strategies of the above. It is beyond the scope of the paper to test all possible strategies in all markets. Rather, the goal is to identify the strategy classes that are simplest and therefore most useful and transportable across markets.

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[15] The larger the search set, the more time the agent will have to react. In my experience, observing prices at three or four stations twice a day (eg. to and from the workplace) is sufficient to observe the trigger.

[16] This phenomenon was observed regularly by the author in this market and other cycling markets.

[17] More accurately, I normalize queueing outside this window to be zero, and take the queueing time of Spike and Buy followers as that which is above and beyond normal queueing times for the given time and day.

4 Results

I now optimize the purchase timing strategies within each class and compare the monetary gains of the optimized strategies across classes. To do this, I generate consumer purchase profiles according to the rules set out by each strategy above for a series of values of X, Y, and Z. I calculate the average price paid according to the generated consumer purchase profile under each strategy using the empirical prices.

The baseline strategy to which all other strategies are compared is the Basic Myopic Strategy. The first row of Table 5 reports the absolute average price paid and markup received for the baseline Basic Myopic Strategy. For all remaining rows, the first and second columns show the percentage change in the average price paid and average markup received under the given row strategy relative to the Basic Myopic Strategy. The third and fourth columns show the absolute change in price and markups in cents per liter relative to the Basic Myopic Strategy. The fifth column reports the number of qualifying possible purchase events in the data for the given row strategy. This is the number of observations over which the average price paid and average markup received are calculated.

The markup is measured as the price minus the rack price minus taxes. Since there are often discounts off the posted rack rate and few buy at the posted rate, it is not unusual for markups as measured to be negative under some strategies. The bias applies to all calculations uniformly, however, and does not affect the comparisons of markups across strategies to follow.[18] Markups can legitimately be negative at the cycle trough if firms use gasoline as a loss leader.

Table 5 reports that the average price paid is 72.53 cents per liter (cpl) and the average markup is 3.31 cpl under the Basic Myopic Strategy. Prices differ little whether the preferred station is operated by a major branded firm or an independent firm. If the consumer's preferred station is a major branded firm, the average price paid is 0.4% above the Basic Myopic Strategy average. If an independent, it is 0.5% below. Weak brand loyalty keeps

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[18] Discounts of a few percent were typical of the period.

price differences across firm types small. Markups are 7% higher for majors and 11% lower for independents relative to the average.[19] I do not report major-preferred and independent-preferred variants of strategies hereafter to conserve space.

The Basic Myopic Strategy can involve a queue when the purchase rule overlaps the Spike and Buy purchase rule. The No-Queue Myopic Strategy avoids this. A consumer using the No-Queue refinement pays 0.4% higher than under the Basic Myopic strategy as they pay the peak price time to time. Markups average 5.4% higher.

It is worth establishing an upper bound to how high average price paid can get. Although not a wise strategy, the *Leader Only Strategy* assumes the consumer only buys from her preferred station when it has just increased price. The average price under this strategy is 3.5% higher and the average markup is 74.4% higher than under the Basic Myopic Strategy.

Now consider strategies that time the cycles. Figure 2 plots the average price paid for a series of threshold values Y for the class of regular Position Based strategies. Thresholds get smaller left to right. Initially as the threshold is reduced from 4, monetary gains increase. However, as Y gets lower, average price paid begins to rise again as the consumer misses more troughs and must purchase close the peak price more often. The figure shows the optimal threshold value of Y is 2 cpl.

Table 5 reports that the monetary gains from using optimized Position Based strategies are significant (2.0 - 2.8%), and the reduction in markups received by firms are also very large (40% - 51%). Average price paid under the Threshold-Equal-2 Position Based Strategy is 2.0% lower than that under the Basic Myopic Strategy. Markups are 41.1% lower. The No-Queue refinement yields almost the same result, since $Y = 2$ is conservatively high enough that queues are rare. The With Delay refinement reduces the penalty from missing a trough and it turns out $Y = 1.5$ is optimal as consumers accept more risk and hold off longer. The average price paid under this refinement falls 2.8% and markups are 51% lower.

Figure 3 plots average price paid for the class of regular X-Day Spike and Wait strategies,

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[19] Markups as measured do not account for other costs that differ between firm types (branding, advertising, quality of product, etc.).

where X varies from 3 to 7 days in half day increments. The figures show that as X increases from 3, average price paid at first falls. Then as X grows large, average price paid rises again since more troughs are missed and the consumer purchases near the peak more often. The figure shows the optimal choice of X for this market is 5.5 days.

Table 5 reports that monetary gains from optimized Spike and Wait strategies range from 1.6% - 2.5% and markups received by firms fall 26% - 48%. Average price paid under the 5.5-Day Spike and Wait Strategy falls 2.1% and average markup falls 36.1% relative to the Basic Myopic Strategy. The No-Queue 5.5-Day Spike and Buy reduces average price paid 1.6% and average markup by 26%. The With Delay refinement reduces average price paid 2.5% and markups by 48.2%.

Figure 4 plots the average price paid for the class of Calendar Based strategies, where each strategy specifies the day of the week and time of day (A.M. or P.M.) to purchase. The figure shows that the greatest monetary gains are from purchasing Monday mornings. Monday evenings or Sundays are good alternate choices, but purchasing just one day too late would erase any gains from a Calendar Based Strategy.

Table 5 reports the monetary gains from optimized Calendar Based strategies range from 1.9% - 2.3% while markups tumble 38% - 45% on these consumers. The Monday AM Calendar Based Strategy reduces the average price paid by 2.3% and average markup by 44.7%. The No-Queue refinement reduces average price paid by 1.9% and markups by 37.5%. The With Delay refinement produces similar gains to the regular version because a Monday AM purchase rule rarely misses a trough. Average price paid falls 2.3% and average markups fall 45.0%.

Finally, Table 5 shows the Spike and Buy Strategy is most effective at timing the trough. It requires significant queueing but, as discussed later, is in clear use by a small minority of consumers. Average price paid under the Spike and Buy strategy falls 3.9% relative to the Basic Myopic Strategy and markups fall 81.9%. Monetary gains are maximized under this strategy and consumers are able to systematically purchase gasoline not only well below the average price but very close to cost. The resulting impact on firm markups is extreme.

The results collectively show that the monetary gains available to consumers from implementing certain optimized timing strategies are potentially large. However, the strategies need to be optimized to be effective, as seen in Figures 2 - 4. Even relatively small deviations from the optimum can erase any potential gains.

In an Edgeworth Cycle, the variation in prices over time (due to the cycle rather than cost changes) should be large relative to the variation in prices across stations at a point in time. To test this, I compare the magnitudes of the monetary gains from intertemporal switching to the monetary gains consumers can achieve from traditional contemporaneous (i.e. cross sectional) price search. Table 6 reports the monetary gains from traditional contemporaneous price search, both separate from and in combination with the gains from intertemporal price search.

Two types of contemporaneous price search are considered. Under Neighbor Search, a consumer follows the prescribed timing strategy and when it comes time to purchase, she compares prices at her preferred station to nearby ones and purchases from the lowest priced one of them. Neighbor stations are chosen to be within a minute's drive of one another, typically at the same intersection, within sight, or within a few blocks of one another on the same street. Stations in the sample have between one and six neighbors. Under Market Search, the consumer compares prices across all twenty-two stations in the sample data spread out along seventeen miles (the eastern part of the city of Toronto) and purchases from the lowest priced station of all of them. The cost to implement the latter search would be large and it is not intended to be a realistic strategy in general, but rather an upper bound to the monetary gain available from intensive contemporaneous search.[20]

Consistent with the theory, Table 6 reports that the potential monetary gains from intertemporal substitution using timing strategies well exceeds those from traditional contemporaneous search. The gains from intertemporal price search are two to four times as great

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[20] Search cost is reduced by using a gas price website, although the cost of driving to the chosen station remains.

as those from Neighbor Search. The gains even exceed those available from the extreme case of a Market Search.

The first row of Table 6 repeats the Basic Myopic Strategy results from the first row of Table 5 without search. The second and third rows allow Neighbor Search. Under the Basic Myopic Strategy with Neighbor Search, the average price paid falls 1.0% and average markup received falls 19.6%. The average price paid under the No-Queue refinement with Neighbor Search falls just 0.4% and markups 8.0%.

The next two rows consider Market Search. The average price paid under the Basic Myopic Strategy with Market Search is 2.2% lower and markups 44.6% lower than with no search. Average price paid under the No-Queue refinement falls 1.3% and markups received fall 27.5%. Because the price distribution at a point in time is so tight, much of the gain from an extensive Market Search can be had from a much narrower Neighbor Search.

Compare these 1% and 2.2% price reductions (from contemporaneous price search, no intertemporal price search) to the timing strategies in Table 5 (intertemporal search, no contemporaneous search). Table 5 reports the Threshold-Equal-1.5 With Delay Position Based Strategy reduces average price paid by 2.8%, the 5.5-Day With Delay Spike and Wait Strategy reduces it by 2.5%, and the Monday AM With Delay Calendar Based Strategy reduces average price paid by 2.3%. The Spike and Buy strategy reduces it by 3.9%. Each of the timing strategies yield greater monetary gains than a Market Search alone and are two to four times as great as from a Neighbor Search alone. I conclude that the opportunity for monetary gain at the current equilibrium is much greater from intertemporal search than from contemporaneous search, both relative to myopic purchasing. While the different types of search surely entail different costs, below I will argue intertemporal search is low not because of the cost of following such a strategy but in large part because consumers are not well informed about the cycles and how to predict prices along them.

Contemporaneous search and intertemporal search is not an either-or choice, of course. Table 6 reports combinations. The Threshold-Equal-2 Position Based Strategy combined with Neighbor Search reduces average price paid by 2.8% and by 3.6% with Market Search. The 5.5-Day Spike and Wait Strategy combined with Neighbor Search lowers average price paid by 2.8% and by 3.9% with Market Search. The Monday AM Calendar Based Strategy with Neighbor Search reduces average price paid by 3.1% or by 3.8% under Market Search. The Spike and Buy Strategy reduces it by 4.5% and 5.3% respectively.

The impact on markups can be extreme. The reduction in markups as measured under the four timing strategies listed in Table 6 are 57%, 52%, 61%, and 94% under Neighbor Search and 74%, 73%, 77%, and 110% under Market Search.

The results collectively show that significant monetary gains are available. Three caveats apply. First, the gains are calculated *at the margin* and conditional on current prices. If timing strategies were to come into wider use, then firms can be expected to adapt to shifting demand patterns and pricing can be affected. If so, purchase timing strategies would need updating en route to a new long run equilibrium. While it is outside the scope of this article to model theoretically how the equilibrium would evolve, later I provide some evidence from Australian markets that more extensive use of purchase timing strategies is unlikely to impact the existence of the cycle itself. The optimized values of X, Y, and Z, though, are likely to evolve.

On a similar note, the purchase timing strategies developed here were optimized for the study market in its 2001 equilibrium. Cycle characteristics vary across markets and also change in response to a variety of exogenous factors. The strategies introduced here need to be reoptimized before their use in this or any market, and then again from time to time as conditions change. If purchase timing strategies are not optimized, the gains from purchase timing strategies can quickly evaporate.

The third caveat is that there are non-monetary costs associated with using these strategies, usually in the form of time and effort spent. For some classes of strategies (e.g. Position Based) they can be significant while for others (e.g. Calendar Based) they are unlikely to be so. Monetary gains from a strategy class would reasonably be left on the table if the implementation costs were high. I argue below that, for at least some consumers, this is not the case. Rather, the reason some purchase timing strategies are not in use is because consumers are not well informed about the cycles or how to time them.

The results of this article yield one more subtle implication. One of the most important questions in the Edgeworth Cycles literature is whether the presence of Edgeworth Cycles has a pro-competitive or anti-competitive effect on prices relative to a stable price equilibrium (Noel (2002), Lewis (2009), Wang (2009b), Lewis & Noel (2011)). A common metric has been to compare average prices in an Edgeworth Cycle equilibrium to those in a stable price equilibrium while controlling for other factors. To the extent that more consumers actually do take advantage of timing strategies, a straight line comparison of average unweighted prices under the two equilibria is likely to be biased *against* finding that Edgeworth Cycles are pro-competitive. In a stable price equilibrium, consumers pay the average price. Under Edgeworth Cycles, they are likely to pay below the average. A more accurate metric would be a comparison of quantity-weighted average prices. The greater the fraction of consumers that time cycles effectively, the lower would be the quantity-weighted average price under Edgeworth Cycles, and the greater the bias against Edgeworth Cycles in the simple average price comparisons used in the literature. Quantity data is not always available, but the bias must be noted.

5 Discussion

Intertemporal Price Discrimination Motives

That the asymmetric pricing pattern in retail gasoline markets are generated by an Edgeworth Cycles process has received support in the empirical literature (Noel (2007a), Noel (2007b), Noel (2008), Eckert (2002), Eckert (2003), Eckert & West (2004), Atkinson (2009), Lewis (2009), Lewis & Noel (2011), Doyle et al. (2008), Wang (2009a) and Wang (2009b)) and in various government investigations (e.g. Conference Board of Canada (2001), the Australian Competition Commission (ACCC) (2007)). Moreover, executives from BP, Caltex, Mobil and other major Australian firms recently testified at a federal investigation in Australia about pricing practices, and their testimony was consistent with prices being set according to an Edgeworth Cycles process rather than intertemporal price discrimination motives (ACCC (2007)).[21]

But it is worth noting that models of pure intertemporal price discrimination can generate similar asymmetric price patterns as well (e.g. Conlisk et al. (1984), Fershtman & Fishman (1992)). These models tend to rely on complete information and foresight by consumers who delay purchases in expectation of lower future prices, causing price to fall slowly in a cyclical fashion. In the Conlisk et al. (1984) discrimination model, for example, there is an ever-growing mass of low willingness to pay consumers that a durable goods monopolist wishes to eventually serve. In the meantime, the monopolist sells to high willingness to pay consumers each period at the highest price it can while ensuring they do not postpone purchases to lower price periods. Price falls slowly over time until it is low enough that the large pent-up demand from low type consumers is finally met, the pressure is relieved, and the process restarts. A cycle similar in appearance to an Edgeworth Price Cycle is created.

Putting aside the above cited studies and executive testimony, the price discrimination story is an unlikely driver for cycles in retail gasoline markets for several reasons. First, as discussed in more detail below, consumers are not perfectly informed, and as a whole appear to be slow to learn about that a cycle exists. Few consumers appear to be use any timing strategy at all in the study market even after years of cycling activity. In practice, expectations about falling prices come well after the cycle has been established, and does not create the cycle in the first place as needed under a price discrimination story.

Second, pent-up demand from consumers with low reservation prices is unlikely. Yatchew & No (2001) and Nocis (2003) estimate the long run elasticity of demand for gasoline in Canada to be about -0.86, and since the amplitude of the cycle is 5.6 cpl, the difference

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[21] BP cites Edgeworth Cycles by name.

in the mean price and bottom of the cycle price is about 3.8% of the mean price. The increase in aggregate demand would be at most 3.3%, and all from the few consumers who knew how to regularly time the cycle. It seems unlikely firms will cycle prices to go after these consumers when they must slash their markups 82% below the mean to get them. Moreover, in relenting phases, leading firms never serve the Spike and Buy consumers, which is the consumer group most associated with buying near the bottom of the cycle. Finally, consumers rarely know wholesale prices and it is unlikely their reservation prices rise and fall with them.

This is not to say that intertemporal considerations cannot be important along an Edgeworth Price Cycle. On the contrary, given established Edgeworth Price Cycles, the purpose of this article is to show that the intertemporal price variation created by the competition cycle is predictable. Many consumers simply appear not to know it.

Cycle Awareness

In spite of relatively sizeable monetary gains, few consumers in the study market use timing strategies. Quantity data are not available, but a combination of evidence from different sources provides a consistent picture. First, I interviewed several dozen station managers and questioned many consumers about gasoline pricing and buying behavior in the study market over the summer of 2001. There is no indication that Position Based strategies or the Spike and Wait strategies were in any use at all over the sample period, nor the very easy Calendar Based strategies.

Guesstimates were that about 5% of consumers used a Spike and Buy strategy at least some of the time. Press reports frequently cite queues of ten to fifteen minutes during the narrow window when this group buys. Unique about the Spike and Buy strategy is that it can be designed and used without underlying knowledge of an asymmetric cycle. Consumers only need to recognize that large price increases at some stations will be followed by large price increases at others.

The lack of use of timing strategies is a paradox, but there is evidence the reason is that consumers were largely unaware there was a predictable cycle in prices.

In June 2001, I conducted a short questionnaire of 58 drivers at several stations in the sample. Respondents were approached at random at two major gasoline stations and one independent in the eastern end of Toronto on four different days.[22] Drivers were asked how frequently they thought prices changed at a given station. The median answer of one day was close to correct (there is a non-zero price change 85% of days). Then respondents were asked what fraction of days they thought the daily price change was a price increase. The mean response was 58%. But in actual fact price increases occurred on only 14% of days. The rest of the time prices were slowly falling. Finally, when asked an open-ended question about whether they noticed any patterns in price movements, only one person of 58 correctly identified a weekly asymmetric price cycle. The lack of learning is intriguing in light of Figure 1 and the fact the cycles had been present for years. But clearly if consumers are not aware of the cycles, they cannot hope to use a timing strategy to take advantage of them.

The lack of awareness is evident in press reports at the time. In the study market, gasoline prices were often a hot topic. Newspaper archives searches of the two major city newspapers in the year up to the end of the sample period reveal several dozen articles touting "high" or "unfair" gasoline prices.[23] Many were printed on the heels of one of the large relenting phase price increases. Some report on queues and quote angry drivers who waited in them. Claims of "price-gouging" and collusion from consumers and calls for investigations were commonplace. Yet I was unable to locate a single article in the two major city newspapers in that year that mentioned the cause of the price increases was a repeated asymmetric cycle. No article mentioned how to predict the troughs or that they could be predicted at all.[24]

When the national television news network CBC (located in Toronto) aired an investiga-

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[22] Roughly equal numbers of respondents were questioned Monday, Tuesday and Wednesday late morning and Thursday early afternoon the week of June 4, 2001.

[23] In April 2001 during the sample period, new all-time record price highs were set with each relenting phase and the dialogue was especially heated.

[24] The two newspapers are the Toronto Sun and the Toronto Star. The first article I found that described an asymmetric cycle was in the national newspaper Globe and Mail in 2004 but it did not give advice on how to time the troughs and made no mention of the strategies described here.

tive consumer report in 1999 on why gasoline prices were high, for example, they made no mention of the cycle that had been present in Toronto and most major Canadian cities for years. Gas price websites whose stated purpose is to help consumers find low prices made no mention of the cycles.

The long held belief of a "long weekend effect" is another indication that consumers were uninformed. An often made complaint from consumers and reported in press articles and government reports (e.g. Conference Board of Canada (2001)) was that gasoline companies were "price-gouging" consumers by sharply increasing prices just prior to long weekends. Putting aside the question of why it would be objectionable for a firm to unilaterally increase its price prior to periods of high demand, Noel (2007b) showed that prices rise sharply during the relenting phase virtually *every* week and there was nothing special about the weeks prior to long weekends. The long weekend effect theory highlights the fact that consumers did not have a complete picture of the Edgeworth Price Cycles.

Comprehensive federal investigations on retail pricing have noted the existence of an asymmetric cycle or "price wars" (e.g. Conference Board of Canada (2001)) but the word is not trickling down to consumers. Reports give no guidance for how to time them.

The Competition Bureau of Canada responded to the volume of questions and complaints with a special FAQ on gas prices on its website, but the information was of little practical use.[25] In response to the question "What causes price swings?", it stated: "[It] is generally an indication that competition is working. Prices fluctuate as retailers compete, and each tries to match what the other is charging." While true, it is not helpful. There is no other mention of cycles in the gas pricing FAQ (Competition Bureau of Canada (2010)).

Finally, and although beyond the sample period, it is worth noting that in 2007 MPP Joe Tascona introduced legislation into the House of Commons that would require gasoline companies to give 72 hours notice prior to any retail gas price increase (and an explanation for it). A quote from the MPP leads this article. If consumers were well informed of how to

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[25] Gas price concerns are contentious enough that gas pricing is one of only seven main topics in the FAQ, and the only industry specific one (Competition Bureau of Canada (2010)).

time the troughs, a 72 hour notice rule would not be of as much help.

These facts all support the conclusion that cycle awareness in the study market was very low. Given this, it is logical that many purchase timing strategies were not in use in spite of their potential value. However, the degree of cycle awareness is better in some other markets with Edgeworth Price Cycles. I am aware of two other surveys of cycle awareness conducted recently for markets that experienced cycles - one from Norway's second largest city Bergen, and one from five major cities in Australia. Unlike in many Canadian and U.S. markets where relenting phases begin on many different days of the week, the Norwegian and Australian markets are weekly and price increases are concentrated on the same day of the week.[26] One might expect cycles in these countries to be more readily identifiable.

Foros & Steen (2008) report a survey of 474 drivers in Bergen, Norway from 2005 and 2006. They report that two thirds of consumers were *not* aware there was a weekly cycle, in spite of the fact that weekly cycles had persisted since at least 2003 and that the large price increases occurred every Monday around noon since April of 2004. While there is learning, it is well short of complete even with an easily predictable peak. The authors report that a large fraction of those aware of the cycle try to buy when gasoline is cheaper.

Cycle awareness in Australia is the exception in Edgeworth Price Cycles markets. Cycles had been present there since at least 1993. Price increases in 2007 were concentrated on Wednesdays or Thursdays, depending on the city.

The cycles have been of much concern to the ACCC who have made efforts to get the word out (ACCC (2007), ACCC (2009)). The ACCC gave a plethora of information on their website to inform consumers about the cycle and how to time them. It had a FAQ, explanations, history, graphs of prices for each city with cycles over the prior 30 days, recommendations on when to buy, and charts comparing the monetary gains from buying on different days of the week (ACCC(2010)). The information is in sharp contrast to the paucity of useful information on the website of its Canadian counterpart.

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[26] The exception was Perth, Australia where cycles were biweekly at the time of the survey, but had been weekly over other periods.

The cycles receive plenty of press coverage in Australia and an online keyword search of "petrol price cycles" returns many relevant hits from leading newspapers in major markets. The articles are explicit about the cycle, its phases, and the timing of relenting phases.

The Australian campaign appears to have the intended effect. ACCC (2007) commissioned a 2007 ANOP consumer survey of 775 people in five major cities where cycles existed. The survey showed that 83% of consumers in eastern markets believed there was a cycle and 75% believed it was weekly. It was lower in Perth, where 61% believed there was a regular price cycle. Only 15% in Perth correctly believed it was (at that time) a biweekly cycle, as it had previously been a weekly cycle. After 17 years of regular cycles and efforts from the ACCC, awareness is significant.

Do Australians use this information? They do. ACCC (2007) reports in the four eastern markets, 59% intertemporally substitute by buying more often on days when they think the price is lower (69% of the fraction that stated cycle awareness). Contrast this with the study market. The Australian experience supports the argument that if consumers are price elastic enough to enable Edgeworth Cycles in the first place, a significant proportion of them are likely to use timing strategies *if* the strategies were simple, *if* they knew they could, and *if* they knew how. A similar information effort can be implemented in other markets with Edgeworth Price Cycles where concern about high gas prices is high but awareness of cycles is low.

Notably, the cycles remain strong and predictable in Australia even with significant use of timing strategies. There is no reason to suspect a cessation of the cycling equilibrium if timing strategies in the study market were to come into widespread use.

The timing of the troughs in most Canadian and U.S. markets with Edgeworth Price Cycles has not been as obvious as in Australia or Norway. But this article shows troughs can be predicted and this information can be made available.

Costs of Using Timing Strategies

Even if consumers were made aware and provided with optimized timing strategies, they must still expect a welfare gain in order to use them. There are non-monetary costs they must incur in order to follow each one. In the end, a consumer will use the strategy that maximizes the monetary gain over the non-monetary cost - be it a timing strategy or a myopic strategy.

So how large are the non-monetary costs for each strategy and which strategies, if any, might expect some significant use in equilibrium if consumers were informed? No direct data is available on the distributions of non-monetary costs across consumers and so it is difficult to predict exactly what the proportions would be. The 5% estimated usage of the Spike and Buy Strategy seems low but plausible if the queues are long. What seems more unlikely is that the near 0% usage of all other timing strategies would persist with informed consumers.

It is worth thinking about this, and a back-of-the-envelope calculation gives us a sense. There are two strategies known to be in use over the sample period - a Myopic Strategy and the Spike and Buy Strategy. There is a marginal consumer who is just indifferent between them. Although I cannot know the non-monetary costs of Spike and Buy for a consumer chosen at random, I can back out the implied non-monetary cost to this *marginal* consumer and ask, for this consumer, is there a more preferable strategy? If so, welfare gains *on the margin* are available.

To conduct the analysis, I identify four main types of non-monetary costs associated with timing strategies. The first is the cost of collecting price information, necessary to predict the timing of the troughs under most timing strategies. The second is the cost of extra visits to the gasoline station to fill up. All timing strategies have this cost because they align purchases with the troughs. On the assumption that a consumer would otherwise only purchase when the fuel gauge got uncomfortably low, she cannot increase the spacing between purchases. She can only reduce it, requiring additional purchase trips at a time cost. If a consumer would normally fill up every week and a half, she would now need to do so every week. The increase in gas station visits can be double for some consumers, and negligible for others, but the added time is constant across timing strategies.

The third cost is the cost of queueing. Significant queueing is common with the Spike and Buy Strategy at peak times although it can occur under other strategies when its purchase rule happens to align with the Spike and Buy purchase rule. The fourth and final cost is the utility cost of brand switching. Timing strategies usually allow consumers to buy from their preferred station, but can require purchasing from a neighboring one on occasion to avoid queues (or peak prices). Brand loyalty is known to be weak and I assume this cost is zero.[27] While there may be other costs, these four have been identified as the most potentially relevant.

The only non-monetary cost associated with the Basic Myopic Strategy is the cost of occasionally queueing when the Spike and Buy consumers happen also to be purchasing. The No-Queue Myopic Strategy avoids has no non-monetary costs at all, and I use this as the baseline case for comparisons.[28]

Position Based strategies have several costs. First is a relatively high cost of information gathering, since consumers must check the rack price online before leaving work or home. Second, it increases the number of visits to the gas station as do all timing strategies. And while queueing is possible, I use the No-Queue Threshold-Equal-2 Position Based Strategy in the calculations to abstract from queues.

Spike and Wait strategies have a small information gathering cost (checking the price billboard at her preferred station each day), and, like other timing strategies, requires more gas station visits. Calendar Based strategies require more station visits as well but have virtually no information gathering costs at all. I use the No-Queue refinements in both cases to eliminate queueing costs.

Finally, there is the Spike and Buy Strategy. The costs of price information gathering is relatively small as it entails no memory of past prices or monitoring of the cycle.[29] I normalize

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[27] Results are similar restricting a consumer to purchase from the same brand type when the strategy requires her to purchase at a station other than her preferred one.

[28] Using the Basic Myopic version while accounting for its occasional queueing costs yields the same conclusions. Using Major-Preferred or Independent-Preferred refinements of the No-Queue strategies yield the same conclusions as well.

[29] The reported "maximum extra time" allowed for price gathering under other strategies in Table 7 should

it to zero. Spike and Buy entails more gas station visits but unlike other strategies, it cannot avoid queues.

Table 7 reports the calculations. According to Transport Canada (2005), the average consumer in Ontario in 2004 drove 17,500 km a year at an average fuel efficiency of 9.1km/L. She purchased 1925 liters of gasoline per year. The average fuel tank capacity is 60.5 liters and assuming she fills her tank whenever the fuel level reaches 1/4 capacity, she would make 42.4 trips to gas stations in a year under a myopic strategy. I calculate that under any timing strategies, she would need an additional 9.6 trips each year (to make 52 trips total, to match the weekly period of the cycle). I assume each fillup takes ten minutes, not including queueing or time buying ancillary products. This implies the additional time spent in a year on visits to the pump to implement a timing strategy is 1.6 hours.

Spike and Buy consumers need to queue. Queue lengths vary but have been observed by the author to reach up to twenty minutes in peak times. Press reports most often quote drivers as waiting ten or fifteen minutes above the norm in queue.

The first column of Table 7 assumes a wait time of 10 minutes (0.17 hours) which would add a total of 8.66 hours per year for queueing, plus 1.6 hours per year for additional trips to the station, for a total of 10.43 hours invested to implement Spike and Buy over that required for the No-Queue Myopic Strategy. Given the 3.0 cpl monetary gain of Spike and Buy over the No-Queue Myopic Strategy from Table 5, this implies a time value to the marginal consumer of $5.54 per hour.

Next, Table 5 shows the monetary gains for the optimized Position Based, Spike and Wait, and Calendar Based strategies are 1.60, 1.39, and 1.58 cpl respectively, relative to the No-Queue Myopic Strategy. Simple calculations then imply that the marginal consumer should prefer a given timing strategy over Spike and Buy if the additional time required to collect price information to implement that timing strategy is less than 3.97, 3.24, and 3.90 hours per year respectively.

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be taken as that *above* what would be required under Spike and Buy. This strengthens the conclusion that other timing strategies yield unrealized welfare gains.

In column 2, where queues are assumed to last 15 minutes, the time value to the marginal consumer indifferent between the Spike and Buy and No-Queue Myopic Strategies is \$3.67 an hour. She should prefer the optimized Position Based, Spike and Wait, or Calendar Based strategy over Spike and Buy if the time required to gather price information for each timing strategy is less than 6.33, 5.29, or 6.23 hours per year respectively.

Is this enough time for the marginal consumer? For the Spike and Wait and Calendar Based strategies, it seems likely to be enough for the consumer at the margin. Spike and Wait requires collecting minimal information - she notes the day the price at her preferred station increases and then buys X days later. The information may take a few seconds or at most a minute a day. The Calendar Based strategy is easier still - it requires no time for information gathering at all. While Spike and Wait may require some self discipline to track prices and count days, the Calendar Based strategy requires nothing more than an awareness of what day of the week it is.

For the Position Based strategy, it is more questionable that this be a preferable option for many. To be preferred to Spike and Buy, the consumer is allowed at most a minute per weekday (column 1) or a minute and a half (column 2) to look up rack prices, check retail prices, and make the necessary calculation. The self discipline required to do so each day may be especially high.

Comparing the three largely unused timing strategies to one another suggests a clear favorite, given the then current equilibrium. The monetary gains of the No-Queue Monday AM Calendar Based strategy are virtually the same as those from the optimized Position Based strategy and a bit greater than those from Spike and Wait. And yet the Calendar Based strategy is the simplest of all timing strategies to implement - it requires effectively zero information gathering effort. I conclude that the marginal consumer at the back of the queue, who was just indifferent between waiting in a queue for ten minutes at a low priced station and buying without wait at a high priced station, would have benefited more by buying at a low price and not waiting in a queue on Monday morning instead.

Interviews with industry participants and a review of newspaper archives have shown few if any knew to do this. It surely seems reasonable that if this strategy was widely known and in significant use, some mention of it would appear in the record given the attention given to gas prices. The Australian experience suggests that when consumers are more aware of effective purchase timing strategies, many use them. The cycle troughs in Canadian and U.S. markets are not so obviously predictable as those in Australia but they are predictable. In conclusion, there are welfare gains to be had by increasing consumer awareness of the cycle and of techniques for how to predict when low prices at the troughs are likely to occur.

6 Conclusion

In a retail gasoline market characterized by Edgeworth Price Cycles, prices predictably and regularly rise and fall by a large amount over the period of the cycle. In the study market of Toronto prices can fluctuate predictably by up to 15% over the course of a week. Consumers can pay a relatively high price or a relatively low one depending on exactly when they purchase, but it appears relatively few know there are cycles at all let alone how to time them.

In this article, I introduced four classes of purchase timing strategies under which informed consumers could lower the average price they pay. The greatest monetary gains, 3.9%, came from the Spike and Buy Strategy. Significant gains were also available under optimized versions of the Position Based, Spike and Wait, and Calendar Based strategies. The monetary gains from these strategies were two to four times greater than those available from a contemporaneous search of nearby stations.

In practice, the Spike and Buy Strategy appeared to be in limited use while other timing strategies were not in measurable use at all. Spike and Buy requires no information about the cycle, but one of the largest time commitments in the form of queueing. I reported evidence in the form of a consumer survey in the study market that consumers were poorly informed about the existence of the cycle generally. Interviews with station managers and consumers, and searches of newspaper archives and other news sources from the study market over the study period support this finding. The lack of learning is surprising given the public interest in gasoline prices, but it is a common theme in many markets with Edgeworth Cycles in Canada and the U.S.

The implication is that if price elastic consumers were informed about the regular cycles and how to time them, there could be immediate welfare gains. In Australia, the ACCC publishes extensive cycle information and 59% of consumers report they intertemporally substitute. While prices in the study market could be affected if newly informed consumers began using purchase timing strategies en masse, the Australian experience shows it is unlikely to destabilize the cycling equilibrium itself. Rather, the timing strategies just need to be reoptimized time to time en route to the new long run price cycle equilibrium.

Even for perfectly informed consumers, implementing timing strategies is not without cost. I report some back-of-the-envelope calculations to suggest that, for a marginal consumer, the monetary gains of using several optimized timing strategies may well exceed the non-monetary costs of implementing them. I conclude that many consumers could experience significant welfare gains if optimized timing strategies were simple, if they knew they could, and if they knew how.

Edgeworth Cycles have now been discovered in the United States, Canada, Australia, and several European nations. The cycles give rise to a natural menu of prices for what is exactly the same physical product. Although not an effort by firms to intertemporally price discriminate, the upshot is that consumers have the option to purchase at a relatively high or relative low price depending on exactly when they buy. In an era of high gasoline prices, this option is an important one to consumers but only useful if they realize they have it.

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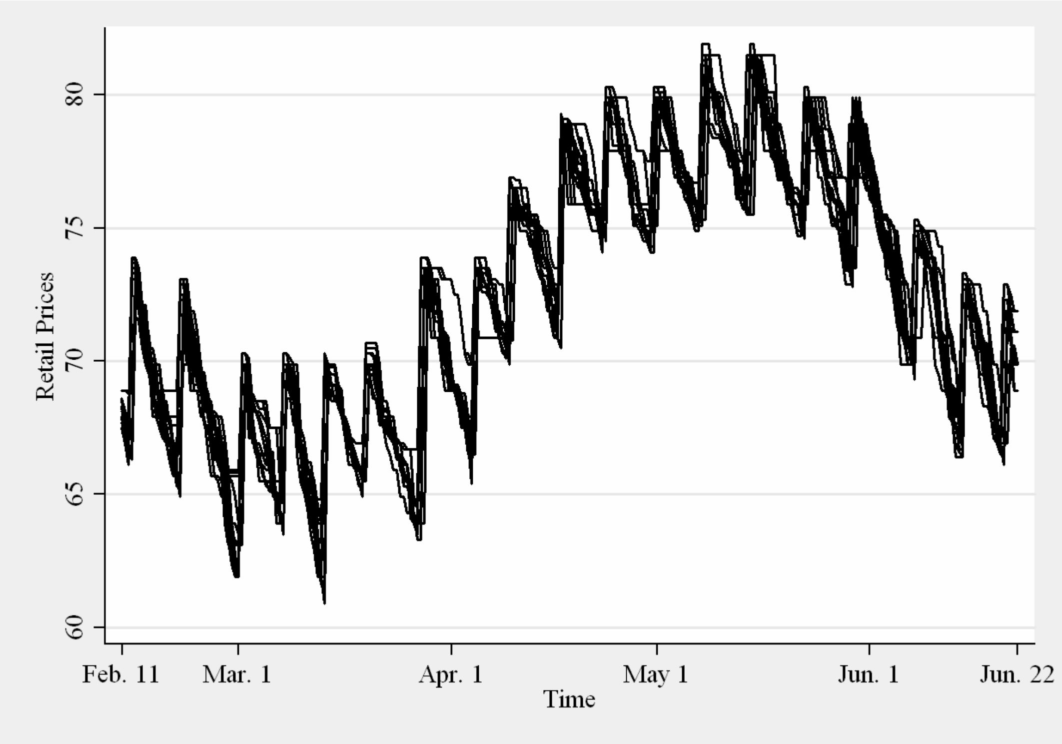

Figure 1: Retail Gasoline Prices in Toronto, 2001

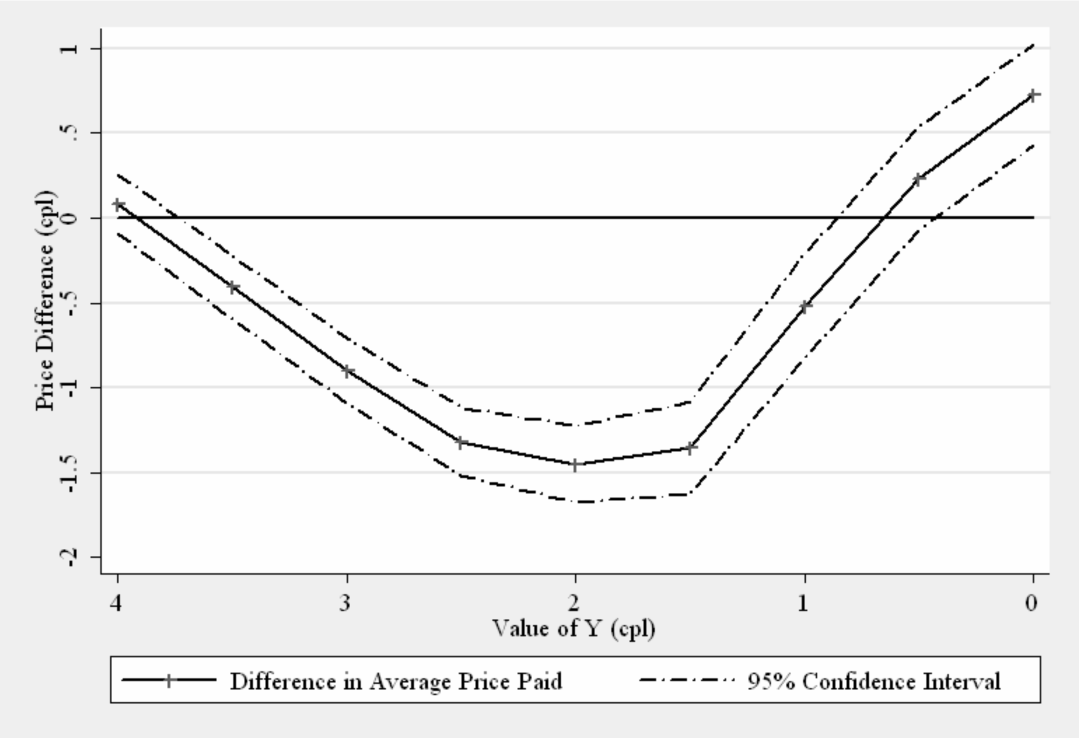

Figure 2: Optimizing the Position Based Strategy

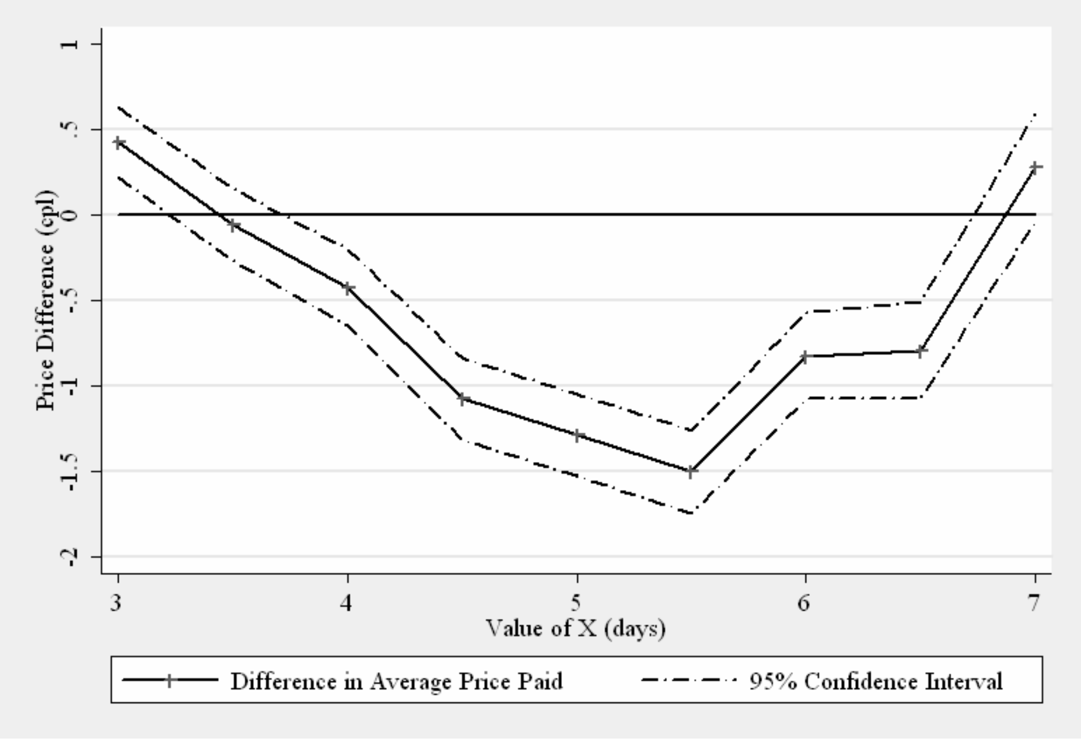

Figure 3: Optimizing the Spike and Wait Strategy

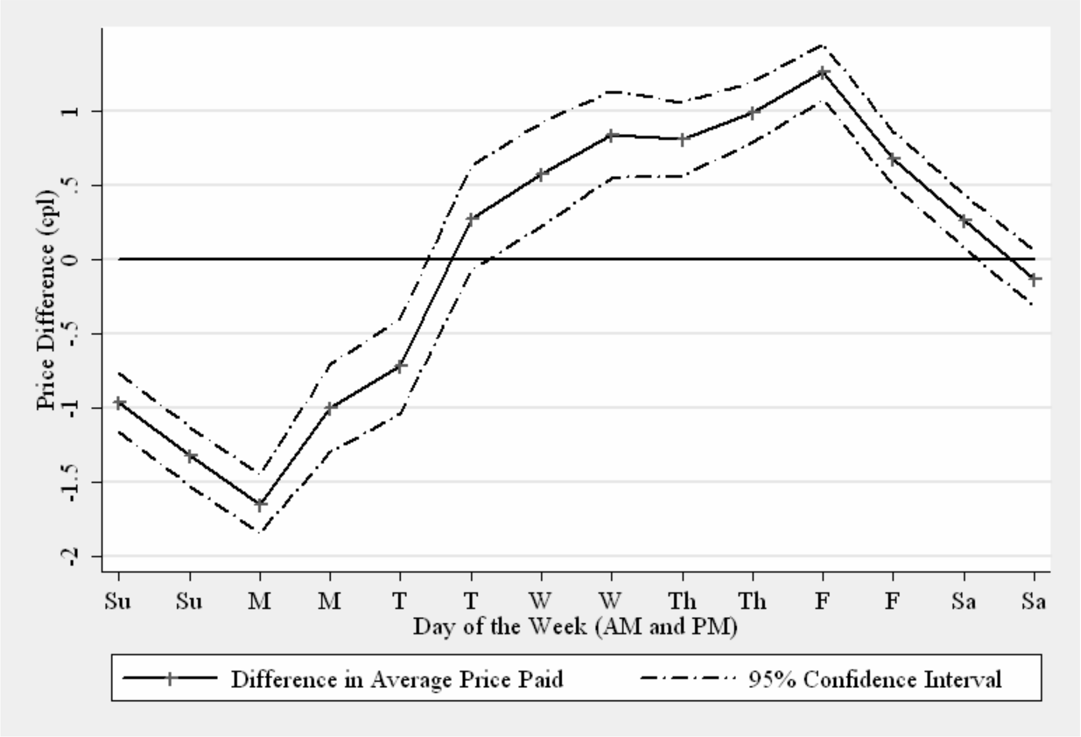

Figure 4: Optimizing the Calendar Based Strategy

Table 1. Summary Statistics

	Mean	Std. Dev.	Minimum	Maximum
RETAIL (price before tax)	43.09	4.44	32.20	51.80
RETAIL (price after tax)	72.53	4.75	60.90	81.90
RACK	39.77	4.00	33.50	46.00
POSITION	3.31	2.08	-3.20	7.60

All values in Canadian cents per liter.

Table 2. Summary Specifications

Specification:	1	2	
	pooled	majors	indeps.
Relenting Phase (dependent variable: $\Delta RETAIL_{st}$)			
$\alpha^R = E(\Delta RETAIL_{st}) \mid I_{st} = "R")$	5.562	5.782	5.242
(average price change)	(0.079)	(0.102)	(0.121)
Undercutting Phase (dependent variable: $\Delta RETAIL_{st}$)			
$\alpha^U = E(\Delta RETAIL_{st}) \mid I_{st} = "U")$	-0.749	-0.767	-0.721
(average price change)	(0.008)	(0.011)	(0.013)
$\gamma^U = Pr(J_{st} = 1 \mid I_{st} = "U")$	0.425	0.418	0.435
(fraction sticky prices)	(0.007)	(0.009)	(0.011)
Switching Probabilities			
λ^{RR} (R to R)	0.007	0.008	0.006
	(0.004)	(0.006)	(0.006)
λ^{RU} (R to U)	0.993	0.992	0.994
	(0.004)	(0.006)	(0.006)
λ^{UR} (U to R)	0.079	0.079	0.079
	(0.004)	(0.005)	(0.006)
λ^{UU} (U to U)	0.921	0.921	0.921
	(0.004)	(0.005)	(0.006)

Standard errors in parentheses.

Table 3. Cycle Characteristics

Specification:	1	2	
	pooled	majors	indeps.
Relenting Phase Duration	1.007	1.008	1.006
	(0.004)	(0.006)	(0.006)
Undercutting Phase Duration	12.729	12.729	12.731
	(0.626)	(0.778)	(0.935)
Cycle Period	13.736	13.737	13.737
	(0.626)	(0.778)	(0.935)
Cycle Asymmetry	12.729	12.627	12.657
	(0.600)	(0.775)	(0.932)
Cycle Amplitude	5.602	5.829	5.273
	(0.081)	(0.101)	(0.127)

Durations and cycle period in half-day periods, amplitude in cents per liter, measure of asymmetry is unit free. Standard errors in parentheses.

Table 4. Regressions of Cycle Components

Specification:	3a	3b	3c	3d
Dependent variable:	λ^{UR} (U to R)	α^{R}	α^{U}	γ^{U}
POSITION	-0.041	-0.953	-0.051	0.004
	(0.006)	(0.030)	(0.006)	(0.005)
RELENTED5	-0.175	0.747	0.059	0.016
	(0.026)	(0.179)	(0.025)	(0.023)
Tuesday	0.056	0.205	-0.159	0.187
	(0.025)	(0.094)	(0.033)	(0.027)
Wednesday	0.058	0.381	-0.069	0.143
	(0.027)	(0.123)	(0.033)	(0.028)
Thursday	0.085	-0.162	-0.077	0.197
	(0.034)	(0.134)	(0.033)	(0.027)
Friday	0.001	0.619	-0.055	0.041
	(0.033)	(0.221)	(0.032)	(0.029)
Saturday	-0.048	-0.656	0.022	-0.021
	(0.045)	(0.187)	(0.028)	(0.028)
Sunday			0.056	0.022
			(0.024)	(0.027)
FOLLOW	0.732	-0.081	0.179	0.282
	(0.038)	(0.099)	(0.099)	(0.083)
MAJOR	0.130	0.519	-0.034	-0.016
	(0.015)	(0.112)	(0.016)	(0.014)
Model	Probit	OLS	OLS	Probit
Month Dummies	Y	Y	Y	Y
Observations	4529	421	3050	5321
R^2	0.51	0.68	0.44	0.03

Standard errors in parentheses. No relenting phases occurred on Sundays in the dataset.

Table 5. Relative Prices and Markups under Timing Strategies

	Relative Change		Absolute Change		Events
	Price	Markup	Price	Markup	
Basic Myopic Strategy	*72.529*	*3.309*	*72.529*	*3.309*	5764
(Absolute Values this line only)	*(0.063)*	*(0.027)*	*(0.063)*	*(0.027)*	
Major-Preferred Basic Myopic Strategy	0.004	0.073	0.261	0.243	3406
	(0.001)	(0.014)	(0.058)	(0.045)	
Independent-Preferred Basic Myopic Strategy	-0.005	-0.106	-0.376	-0.352	2358
	(0.001)	(0.015)	(0.064)	(0.048)	
No-Queue Myopic Strategy	0.004	0.054	0.261	0.180	5764
	(0.001)	(0.011)	(0.058)	(0.038)	
Leader Only Strategy	0.035	0.744	2.569	2.461	421
	(0.001)	(0.015)	(0.095)	(0.049)	
Threshold-Equal-2 Position Based Strategy	-0.020	-0.411	-1.450	-1.360	435
	(0.002)	(0.024)	(0.115)	(0.080)	
No-Queue Threshold-Equal-2 Position Based Strategy	-0.020	-0.403	-1.421	-1.332	435
	(0.002)	(0.024)	(0.117)	(0.081)	
Threshold-Equal-1.5 With Delay Position Based Strategy	-0.028	-0.509	-2.016	-1.684	437
	(0.002)	(0.025)	(0.130)	(0.084)	
5.5-Day Spike and Wait Strategy	-0.021	-0.361	-1.501	-1.194	420
	(0.002)	(0.028)	(0.124)	(0.094)	
No-Queue 5.5-Day Spike and Wait Strategy	-0.016	-0.260	-1.142	-0.859	420
	(0.002)	(0.031)	(0.126)	(0.104)	
5.5-Day With Delay Spike and Wait Strategy	-0.025	-0.482	-1.812	-1.594	400
	(0.002)	(0.022)	(0.113)	(0.072)	
Monday AM Calendar Based Strategy	-0.023	-0.447	-1.651	-1.479	418
	(0.001)	(0.025)	(0.101)	(0.084)	
No-Queue Monday AM Calendar Based Strategy	-0.019	-0.375	-1.396	-1.240	418
	(0.002)	(0.027)	(0.114)	(0.089)	
Monday AM With Delay Calendar Based Strategy	-0.023	-0.450	-1.661	-1.489	418
	(0.001)	(0.025)	(0.100)	(0.083)	
Spike and Buy Strategy	-0.039	-0.819	-2.827	-2.710	203
	(0.003)	(0.026)	(0.182)	(0.087)	

Event column reports the number of possible purchase events for given purchase profile. First row reports absolute price and markup under Basic Myopic Purchase Profile. Other rows report change in price and markup levels and percentages for given purchase profile relative to the first row. Regressions include month dummy variables. Prices and markups (and level changes) in Canadian cents per liter.

Table 6. Prices and Markups under Timing Strategies with Search

	Relative Change		Absolute Change		Events
	Price	Markup	Price	Markup	
Basic Myopic Strategy	*72.529*	*3.309*	*72.529*	*3.309*	5764
with No Search *(Absolute Values this line only)*	*(0.063)*	*(0.027)*	*(0.063)*	*(0.027)*	
Basic Myopic Strategy	-0.010	-0.196	-0.695	-0.650	5764
with Neighbor Search	(0.001)	(0.011)	(0.050)	(0.038)	
No-Queue Myopic Strategy	-0.004	-0.080	-0.284	-0.265	5764
with Neighbor Search	(0.001)	(0.012)	(0.050)	(0.039)	
Basic Myopic Strategy	-0.022	-0.446	-1.579	-1.475	5764
with Market Search	(0.001)	(0.011)	(0.048)	(0.037)	
No-Queue Myopic Strategy	-0.013	-0.275	-0.975	-0.911	5764
with Market Search	(0.001)	(0.011)	(0.049)	(0.038)	
Threshold-Equal-2 Position Based Strategy	-0.028	-0.569	-2.009	-1.882	435
with Neighbor Search	(0.002)	(0.021)	(0.112)	(0.069)	
Threshold-Equal-2 Position Based Strategy	-0.036	-0.744	-2.629	-2.461	435
with Market Search	(0.002)	(0.019)	(0.110)	(0.062)	
5.5-Day Spike and Wait Strategy	-0.028	-0.515	-2.048	-1.705	420
with Neighbor Search	(0.002)	(0.027)	(0.123)	(0.088)	
5.5-Day Spike and Wait Strategy	-0.039	-0.727	-2.798	-2.406	420
with Market Search	(0.002)	(0.023)	(0.116)	(0.076)	
Monday AM Calendar Based Strategy	-0.031	-0.612	-2.235	-2.025	418
with Neighbor Search	(0.001)	(0.023)	(0.096)	(0.077)	
Monday AM Calendar Based Strategy	-0.038	-0.766	-2.780	-2.534	418
with Market Search	(0.001)	(0.021)	(0.089)	(0.069)	
Spike and Buy Strategy	-0.045	-0.937	-3.242	-3.099	203
with Neighbor Search	(0.002)	(0.025)	(0.133)	(0.084)	
Spike and Buy Strategy	-0.053	-1.104	-3.834	-3.652	203
with Market Search	(0.002)	(0.024)	(0.128)	(0.081)	

Event column reports the number of possible purchase events for given purchase profile. First row reports absolute price and markup under Basic Myopic Purchase Profile. Other rows report change in price and markup levels and percentages for given purchase profile relative to the first row. Regressions include month dummy variables. Prices and markups (and level changes) in Canadian cents per liter.

Table 7. Strategy Optimization for the Marginal Consumer

	10 min. Queue	15 min. Queue
Calibrated Values for the Marginal Consumer		
Kilometers Driven per Year (km/yr)	17,500	17,500
Average Fuel Efficiency (km/L)	9.09	9.09
Average Purchase Size (L)	45.38	45.38
Annual Quantity (L/yr)	1,925	1,925
Estimating the Value of Time to Marginal Consumer		
Monetary Gain of *Spike and Buy* over No-Queue Myopic Strategy (c/L)	3.00	3.00
Time Cost of Queueing to Marginal Consumer if using *Spike and Buy* (hrs/trip)	0.17	0.25
Time Cost of Queueing to Marginal Consumer if using *Spike and Buy* (hrs/yr)	8.66	13.00
Time Cost of Additional Purchase Trips to Marginal Consumer with Spike and Buy (hrs/yr)	1.60	1.60
Total Time Cost of *Spike and Buy* Strategy to Marginal Consumer (hrs/yr)	10.43	14.85
Estimated Marginal Value of Time to the Marginal Consumer ($/hr)	5.54	3.89
Monetary Gains relative to No-Queue Basic Myopic Strategy		
No-Queue Threshold-Equal-2 Position Based Strategy (c/L)	1.60	1.60
No-Queue 5.5-Day Spike and Wait Strategy (c/L)	1.39	1.39
No-Queue Monday AM Calendar Based Strategy (c/L)	1.58	1.58
Maximum Time for Information Gathering for Strategy to be Preferred		
Maximum Extra Time for Information Gathering (hr/yr) for Position Based to be preferred to Spike and Buy	*3.97*	*6.33*
Maximum Extra Time for Information Gathering (hr/yr) for Spike and Wait to be preferred to Spike and Buy	*3.24*	*5.29*
Maximum Extra Time for Information Gathering (hr/yr) for Calendar Based to be preferred to Spike and Buy	*3.90*	*6.23*

Calibrated Values for the Marginal Consumer taken from Transport Canada (2005). Monetary gains over No-Queue Myopic Strategies from Table 5. Monetary gain of Spike and Buy Strategy used to calibrate the Marginal Value of Time to the Marginal Consumer (based on monetary gain from using Spike and Buy and amount of time to implementing it). Marginal Value of Time combined with Monetary Gains from other timing strategies to calculate the maximum amount of time marginal consumer would be willing to invest to implement other timing strategies. Column 1 assumes a 10 minute queue under Spike and Buy and Column 2 assumes a 15 minute queue.