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Asymmetric Price Adjustment and Consumer Search: An Examination of the Retail Gasoline Market

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It has been documented that retail gasoline prices respond more quickly to increases in wholesale price than to decreases. However, there is very little theoretical or empirical evidence identifying the market characteristics responsible for this behavior. This paper presents a new theoretical model of asymmetric adjustment that empirically matches observed retail gasoline price behavior better than previously suggested explanations. I develop a "reference price" consumer search model that assumes consumers' expectations of prices are based on prices observed during previous purchases. The model predicts that consumers search less when prices are falling. This reduced search results in higher profit margins and a slower price response to cost changes than when margins are low and prices are increasing. Following the predictions of the theory, I use a panel of gas station prices to estimate the response pattern of prices to a change in costs. Unlike previous empirical studies I focus on how profit margins (in addition to the direction of the cost change) affect the speed of price response. Estimates are consistent with the predictions of the reference price search model, and appear to contradict previously suggested explanations of asymmetric adjustment.

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1 Introduction

A large empirical literature provides evidence that retail gasoline prices respond faster to cost increases than to cost decreases.[1] The California retail gasoline price series displayed in Figure 1 clearly demonstrates such asymmetric adjustment to wholesale cost. However, little previous research has attempted to formally model or empirically identify which characteristics of the retail gasoline market may be responsible for asymmetric price adjustment.[2] This paper presents a new model of asymmetric adjustment with predictions that empirically match observed retail gasoline price behavior better than previously suggested theories.

Asymmetric price adjustment is not unique to the gasoline market. The phenomenon has been observed and studied in a variety of industries.[3] As Peltzman (2000, p.468) points out, the prevalence of asymmetric price adjustment suggests "a serious gap in a fundamental area of economic theory." I develop a model of asymmetric adjustment that helps bridge this gap. Although the model was inspired by the behavior of retail gasoline consumers, it is general enough to be applied to other industries with similar consumer search characteristics.

Gasoline price behavior is often associated with consumer search.[4] I focus on a particular type of consumer search behavior that could result in the asymmetric response of equilibrium retail prices to wholesale cost changes. The model, which I refer to as the *reference price search model*, assumes that searching consumers' expectations of prices are based on prices observed during previous purchases.[5] As a result, if a consumer observes a price that is low relative to last

[1]Academic research addressing asymmetric adjustment of gasoline prices includes: Borenstein, Cameron & Gilbert (1997), Bacon (1991), Karrenbrock (1991), Duffy-Deno (1996), Johnson (2002), and Eckert (2002). Existing policy studies include: GAO (1993), DOE/EIA (1999), and Finizza (2002).

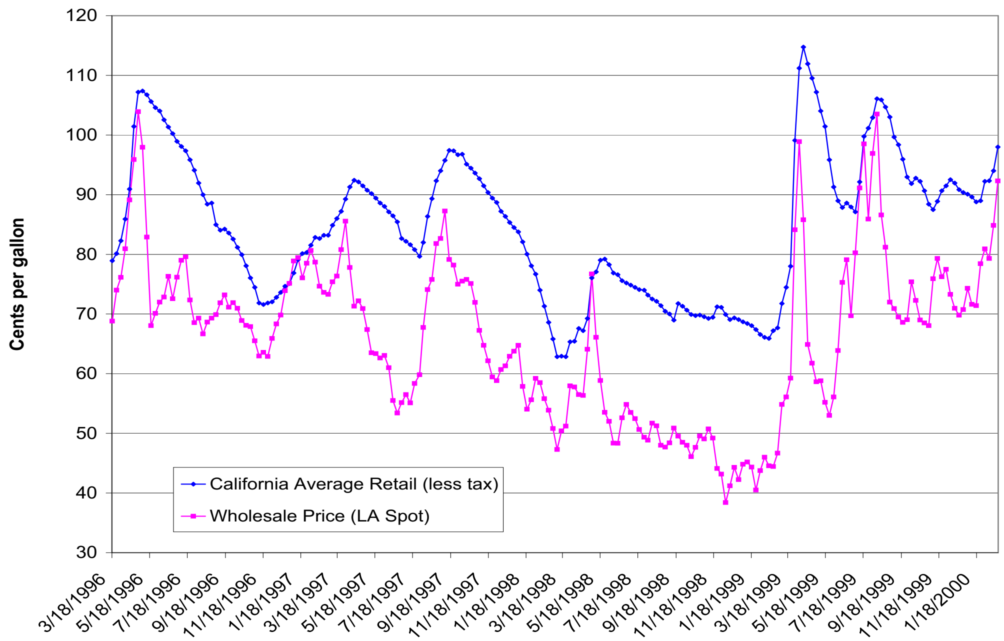
[2]Johnson (2002) finds that diesel prices respond more quickly and less asymmetrically than gasoline prices to a change in costs. He suggests that this behavior may be consistent with a model of consumer search similar to the model developed in this paper. Eckert (2002) shows that Edgeworth Cycle equilibria can produce asymmetric adjustment and presents some empirical support using gasoline prices from Windsor, Ontario. However, the Edgeworth Cycle theory used by Eckert (2002) and Noel (2002) describes markets where retail prices frequently cycle up and down independently of wholesale cost. This price behavior is not observed in my sample or in the gasoline prices of most U.S. cities.

[3]Peltzman (2000) examines prices in over 200 industries and finds evidence of asymmetric adjustment in a significant share of the sample. In addition, Goodwin and Holt (1999) and Goodwin and Harper (2000) estimate asymmetric adjustment in the U.S. beef and pork industries, and O'Brien (2000) estimates asymmetric adjustment in interest bearing deposit accounts.

[4]See pioneering work by Marvel (1976).

[5]The term "reference price" refers to the external price (last period's price) consumers use to compare with observed prices. The marketing literature uses this term to describe a very similar concept. Appendix B contains a discussion of how this model fits into the marketing literature.

Figure 1: California Gasoline Prices 1996-2000.[a]



[a]Retail prices are California average prices from the California Energy Commission (minus applicable taxes). Wholesale prices are weekly averages of the Los Angeles spot market prices from the Dept. of Energy (EIA).

period's price, he perceives that there is only a small probability that he will find an even lower price by searching. Therefore, consumers are less likely to search when price levels are lower than expected. When fewer consumers search, firms face more inelastic residual demand curves implying less competition between firms and higher price-cost margins. This illustrates the fundamental relationship between consumer search activity and profit margins in this model.

The relationship between search and margins is best conveyed by analyzing extreme cases in which marginal costs are much higher or much lower than consumers' expectations of price. If marginal cost rises well above last period's price, firms are forced to charge higher prices than consumers expect. As a result, all consumers choose to search. When all consumers search, the model reduces to a full information model of homogeneous product Bertrand competition in which prices equal marginal cost. Therefore, high search activity and low margins result when cost rises above price expectations. Alternatively, if marginal cost falls well below last period's price, firms lower their prices just enough to prevent consumers from searching. Although margins are high, consumers are not searching, so firms are unable to attract more customers by lowering price.

Consumers' expectations for next period's price remains almost as high, since price only fell slightly this period. So, prices fall slowly and margins remain high in subsequent periods because firms continue to lower prices only enough to prevent search each period. During high margin periods, the level of wholesale cost does not affect equilibrium prices. Firms price strictly to prevent search. As a result, one testable implication of the model is that equilibrium prices only respond to cost changes when margins are small.

In this model, asymmetric adjustment occurs because prices respond to cost only when cost is near or above last period's price. This usually happens following large increases in marginal cost. Price responds immediately in order to remain at or above marginal cost. When costs fall, margins increase and firms respond by lowering price just enough to prevent search. This partial response means that equilibrium prices adjust more slowly to negative cost changes than to positive cost changes.

The reference price search model captures the importance of consumer's expectations by making one crucial assumption which differs from the previous search literature. Most search models assume that consumers know, *a priori*, the distribution of equilibrium prices that firms charge in the market.[6] Consumer search decisions are based on this known distribution. This assumption creates an equilibrium in which both consumers and firms are acting optimally given the final price distribution. However, in many applied situations, consumers are likely to have a difficult time gaining knowledge of the current distribution of prices. This is particularly likely in markets where cost fluctuations produce rapidly changing price distributions. My model limits the amount of information consumers are assumed to have.[7] Consumers construct a perceived distribution of prices using price information from previous periods, and make search decisions accordingly. Both firms and consumers still behave optimally given this reduced information. However, consumers search optimally from the perceived distribution and firms optimally set prices which may be different than the perceived distribution. The result is that prices respond

[6] Examples include Salop & Stiglitz (1977) or Rob (1985).

[7] Another way to relax the assumption of a known price distribution is to assume that the distribution is initially unknown and knowledge of the distribution is built up by searching. See for example Rothschild (1974). This approach is also unappealing in markets where consumers search relatively few times before each purchase and price distributions change substantially between purchases. If search is relatively costly then the prior distribution becomes very important, which mirrors the case described in my model.

asymmetrically to cost changes.

The reference price search model provides a new possible explanation for the unconventional price adjustment dynamics observed in the retail gasoline market. Following the insights of this model, my empirical examination of retail gasoline prices goes beyond just measuring whether prices rise more quickly than they fall. The reference price search model generates different equilibrium price dynamics when margins are high than when they are low. My empirical work documents how price dynamics and price response are related to profit margins in the gasoline market.

Much of the empirical analysis relies on estimating the dynamic relationship between the retail price and wholesale cost of gasoline. To do so, I model the expected retail price conditional on past values of price and wholesale cost. Using a panel of gas station prices, I estimate an adapted autoregressive model that allows the nonlinear and asymmetric relationships predicted by the theoretical model. With these estimates I can characterize how prices respond to various types of cost changes under different market conditions. A panel dataset of station prices enables me to estimate market wide responses as well as station specific responses to cost changes.

Since price and cost are cointegrated, I estimate an error-correction form of the autoregressive model using the techniques developed by Engle & Granger (1987) and Stock (1987). The coefficients are estimated separately for periods of high margins and low margins using a threshold autoregression. This allows for the differences in response behavior predicted in the reference price search model. Following the previous literature, I also separately estimate the coefficients of positive and negative lagged changes in price and cost. The four sets of coefficients produce separate estimates of the response to a positive or negative cost shock in a low or high margin period. These estimates allow changes in observed response behavior to be compared with the predictions of the reference price search model as well as previous empirical results and alternative theories of asymmetric adjustment.

The results indicate that margins are high when prices are falling and low when prices are rising. Prices respond much more slowly to both positive and negative cost shocks when profit margins are high. There also appears to be very little variation across firms in response behavior. These results are consistent with the predictions of the reference price search model presented in this paper. However, some of these findings challenge existing empirical evidence on the response of retail gasoline prices to cost changes. Previous studies have found that price responded faster to positive cost changes than negative cost changes. The empirical results of this paper suggest that margin size may be a much more important determinant of the speed of price response. By controlling for the size of current margins, I estimate that there is little difference in response behavior to a positive and negative cost change. Overall, asymmetric adjustment still occurs since positive cost shocks tend to lead to low margins and fast response, and negative cost shocks lead to high margins and slow response.

2 Reference Price Search Model

This model derives equilibrium prices for a market in which searching consumers base expectations of the prices they will find on past equilibrium prices. Though motivated by the attempt to explain asymmetric adjustment in retail gasoline markets, its structure is fairly general. It applies to any market in which searching consumers repeatedly purchase a product that has significant price variation over time. To make the proofs more intuitive and the notation easier, I assume that the market has only 2 firms. The model can be generalized to allow for any number of firms. I first specify a static model of local station competition and consumer search. Then I create a dynamic model by repeating the static game and allowing consumer price information to be a function of the equilibrium prices in previous periods. This captures the intuition that consumers are only aware of prices they have paid or observed in the past.

2.1 Static Model

Consider a market with 2 identical firms producing a homogeneous good. Both firms have zero fixed costs and a marginal cost c.[8] There are N consumers who each have unit demand for the good (up to a very high price). Consumers' expectations of prices are defined by a distribution with a continuous c.d.f. of $L(p)$ and p.d.f. of $l(p)$ (which are identical for all consumers). These

[8]Fixed (sunk) costs are irrelevant here since I am only studying the short run dynamics of competition between firms. They are assumed to be zero for notational simplicity.

expectations are assumed to be exogenously determined in the static game.[9] Consumers do not observe any information about marginal cost.[10] Each consumer randomly observes the price at one of the firms. Then the consumer must choose between purchasing from that firm or paying a constant search cost k to observe the other firm's price. Search costs are randomly distributed across all consumers with a continuous c.d.f. of $G(k)$ and strictly positive support. Once a consumer chooses to search, he may purchase from either firm at no additional cost.

Henceforth, the two firms are called firm 1 and firm 2, and the consumers who originally observed the price at firm 1 are called firm 1's consumers. The prices the firms charge are p_1 and p_2 respectively. Since the firms are identical and the consumers of each firm are identical, any result about firm 1's behavior also holds for firm 2. After observing p_1, firm 1's consumers search if their expected value of finding a p_2 below p_1 is greater than the cost of searching. This occurs when:

$$\int_0^{p_1} (p_1 - p_2) l(p_2) \mathrm{d}p_2 > k$$

Define $S(p)$ as the fraction of consumers from one station who choose to search, so that:

$$S(p_1) = G\left(\int_0^{p_1} (p_1 - p_2) l(p_2) \mathrm{d}p_2\right).$$

Assume that the distribution of search costs $G(k)$ has a compact support and satisfies the monotone hazard rate condition.[11] (The compact support is not necessary but leads to a more intuitive exposition). Because $G(k)$ has a monotone hazard rate, S(p) also satisfies the monotone hazard rate condition and has a compact support. As a result, there exists some price p^{ns} below which no consumers search ($S(p^{ns}) = 0$) , and some price p^{as} above which all consumers search ($S(p^{as}) = 1$). Each consumer has a reservation price above which they will search, and $S(p)$ can also be thought

[9]It is common for models to assume that consumers know the distribution of prices being charged in the market, but not the specific price locations. See for example, Salop & Stiglitz (1977) or Rob (1985). The only difference in this model is that consumers may perceive a distribution of prices which is not equal to the actual distribution. The amount of information that consumers have is lower than what previous models assume. This is an attempt to more realistically capture the knowledge consumers have about gasoline prices. In the specification of the dynamic model these expectations will become a function of past equilibrium prices.

[10]In the gasoline market (and many other markets) this assumption is fairly accurate. Consumers generally have little knowledge of wholesale gas prices. Intermittent news reports often focus on retail prices or oil prices. Detailed knowledge of oil price movements is probably unusual, and refinery conditions cause wholesale gasoline prices to frequently move independently of oil prices.

[11]The monotone hazard rate assumption is that $\frac{\mathrm{d}}{\mathrm{d}p}\left(\frac{g(p)'}{1-g(p)}\right) \geq 0$. This is a common assumption which insures a unique profit-maximizing solution.

of as the distribution of these reservation prices.

The hazard rate of S(p) has an important significance in this model. One can interprete the hazard rate $\left(\frac{S'(p)}{1-S(p)}\right)$ as the share of the firm's non-searching consumers who choose to search if the firm raises p slightly. For later convenience I define $\phi(p)$ as the inverse hazard rate of $S(p)$:

$$\phi(p) = \begin{cases} \frac{1-S(p)}{S'(p^-)} & : \quad p = p^{as} \\ \frac{1-S(p)}{S'(p)} & : \quad p^{ns} \leq p \leq p^{as} \\ \frac{1-S(p)}{S'(p^+)} & : \quad p = p^{ns} \end{cases}$$

where

$$S'(p^+) = \lim_{p \downarrow p^{ns}} S'(p^{ns}) \quad and \quad S'(p^-) = \lim_{p \uparrow p^{as}} S'(p^{as}).$$

The relative values of c and $L(p)$ (and therefore p^{ns} and p^{as}) determine how competitive the market is. Once p is low enough that some of the firm's consumers are not searching, the firm becomes a monopolist over the demand from its non-searching consumers. Now no other firm can steal these customers by offering a lower price. Since $\frac{N}{2}$ customers initially observe each firm's price, the firm's initial demand from non-searching consumers is simply: $x^{ns}(p) = \frac{N}{2}[1 - S(p)]$. Even though consumers have perfectly inelastic demand for the good, the firm's demand from non-searching consumers has elasticity due to the possibility of search. When the firm raises its price, some of its non-searching customers decide to search.

The firm also sells to all the searching consumers in the market if it has the lowest price. The total demand for firm 1 is:

$$x_1(p_1) = \frac{N}{2}\Big[1 - S(p_1) + \mathbf{1}(p_1 < p_2)[S(p_1) + S(p_2)]\Big]$$

where $\mathbf{1}(p_1 < p_2)$ represents an "indicator function" that equals one if searching consumers choose firm 1, zero otherwise. The profit function for firm 1 is:

$$\pi(p_1) = \frac{N}{2}(p_1 - c)\Big[1 - S(p_1) + \mathbf{1}(p_1 < p_2)[S(p_1) + S(p_2)]\Big].$$

It is necessary to allow for the possibility of mixed strategies. Let $F_i(p)$ represent the distribution function and $f_i(p)$ the density function of firm i's mixed strategy, with support $[\underline{p_i}, \overline{p_i}]$. Then Firm 1's expected profit given Firm 2's strategy $f_2(p)$ is:

$$\Pi(p_1) = \frac{N}{2}(p_1 - c)\left[(1 - S(p_1)) + \int_{p_1}^{\overline{p_2}} [S(p_1) + S(p_2)] f_2(p_2) \mathrm{d}p_2\right]$$

The expected profit function can be decomposed into a profit function for non-searching consumers and an expected profit function from searching consumers, $\Pi = \Pi^{ns} + \Pi^{s}$ such that:

$$\Pi_1^{ns}(p_1) = \frac{N}{2}(p_1 - c)(1 - S(p_1)) \quad \text{and} \quad \Pi_1^{s}(p_1) = \frac{N}{2}(p_1 - c)\int_{p_1}^{\overline{p_2}} [S(p_1) + S(p_2)] f_2(p_2) \mathrm{d}p_2.$$

A fundamental principle of the model is that p_2 does not affect the profits firm 1 receives from its non-searching consumers. No matter how aggressively the competition sets prices, firm 1 can earn positive profits by setting a price so that some of his consumers don't search (as long as c is not too high).

Lemma 1 $\Pi^{ns}(p)$ *is uniquely maximized over the range* $[p^{ns}, p^{as}]$ *at* $\mathrm{argmax}_p \Pi^{ns}(p) = \tilde{p}$ *such that* $\tilde{p} = \phi(\tilde{p}) + c$ *and* $\max_p \Pi^{ns}(p) = \frac{N}{2}(\tilde{p} - c)^2 S'(\tilde{p}) = \left(\frac{N}{2}\right) \frac{(1-S(\tilde{p}))^2}{S'(\tilde{p})}$.

Proof: See Appendix A.

This result identifies the price, $\tilde{p}$, which maximizes a firm's profits from its non-searching consumers. It is the price that equates the marginal benefit of earning higher profit margins from non-searching consumers with the marginal cost of causing some of your non-searching consumers to search by increasing price. The strategy of maximizing profits from non-search consumers becomes important as an alternative when competing for searching consumers becomes too costly.

The existence of a price below which no consumers will choose to search, p^{ns}, implies another simple but important result of the model. If p is low enough that all consumers purchase from their initial station, no firms have an incentive to lower price further. As a result, firms will never charge a price below p^{ns}.

Lemma 2 *Values of* p *such that* $p < p^{ns}$ *are strictly dominated.*

Proof: See Appendix A.

2.1.1 Pure Strategy Equilibria

Given these results, it is now possible to describe the competitive equilibrium. The relative parameter values of marginal cost (c), the *all-search price* (p^{as}), and the *no-search price* (p^{ns}) affect the nature of the equilibrium. Therefore, the equilibrium prices are described conditional on the value of c.

Proposition 1 *The following properties of the pure strategy equilibria can be characterized:*

1. If $c \geq p^{as}$ *, all consumers search and* $p_1 = p_2 = c$ *is the unique equilibrium.*

2. If $p^{ns} - \phi(p^{ns}) < c < p^{as}$ *, some consumers search and no pure strategy equilibrium exists.*

3. If $c \leq p^{ns} - \phi(p^{ns})$ *, no consumers search and* $p_1 = p_2 = p^{ns}$ *is the unique equilibrium.*

Proof: See Appendix A.

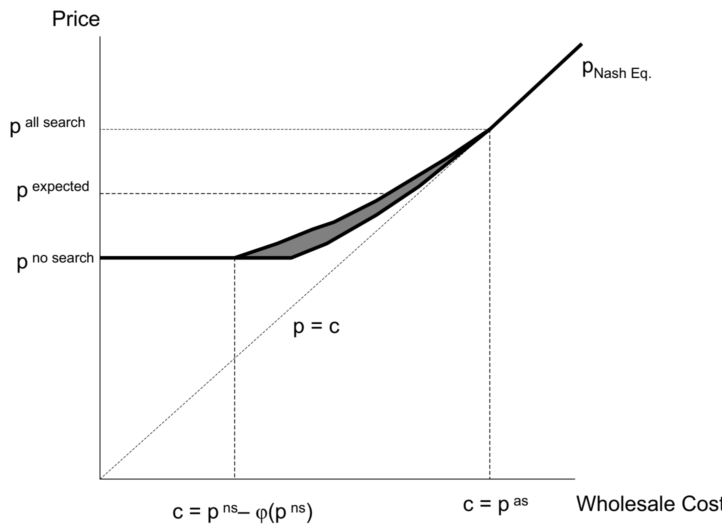
In cases where a pure strategy equilibrium exists, either all consumers are searching or no consumers are searching. If $c > p^{as}$, firms must charge $p > p^{as}$, and all consumers search. The outcome is identical to that of a full information, homogeneous product Bertrand model. If c is low firms have an incentive to charge a low p, but they never charge $p < p^{ns}$ (Lemma 2). So for low values of c, firms charge $p = p^{ns}$ and no consumers search. For intermediate values of c some but not all consumers search and no pure strategies exist. A firm's best response is almost always to slightly undercut the other firm's price in order to steal the searching consumers. However, at prices close to c, firms are be better off disregarding the searching consumers and raising price to make profits from non-searchers. No pure strategy exists since a firm's best response is either to slightly undercut the other firms price or price well above the other firm. This is similar to the mixed strategy equilibrium found in the informed/uniformed consumer model of Varian (1980).

The equilibrium prices of the symmetric firms for each level of c are illustrated in Figure 2. The example depicted represents the case where the distribution of search costs, $G(k)$, is uniform and beliefs about the distribution of prices, $L(p)$, is normal. The next section discusses the bounds of the support of the mixed strategy equilibria that are represented by the shaded portion of the graph.

2.1.2 Mixed Strategy Equilibria

A mixed strategy equilibrium results from c in the range $\left(p^{ns} - \phi(p^{ns}), p^{as}\right)$. For $c < p^{as}$ any mixed strategy equilibria must have positive expected profits since the firm can charge a price p such that $c < p < p^{as}$ and make positive profits by selling to non-searching consumers. Therefore, the expected profits from a mixed strategy equilibrium must be at least as large as the maximum profit firms could make by selling to only non-searching consumers (which is calculated in Lemma 1).

Figure 2: Nash equilibria prices for different states of C.



Lemma 3 *For* $c \in \Big(p^{ns} - \phi(p^{ns}), p^{as}\Big)$ *an equilibrium mixed strategy must have expected profit* $\Pi \geq (\tilde{p} - c)^2 S'(\tilde{p})$ *where* $\tilde{p}$ *is defined by* $\tilde{p} = \phi(\tilde{p}) + c$.

Proof: See Appendix A.

I do not fully derive the distribution of the equilibrium mixed strategy, but I describe the equilibrium expected profit level as well as several properties of the equilibrium support.

Proposition 2 *For c in the range* $\Big(p^{ns} - \phi(p^{ns}), p^{as}\Big)$ *an equilibrium mixed strategy* $F(p)$ *over the support* $[\underline{p}, \overline{p}]$ *has the following properties:*

1. $\overline{p} = \tilde{p}$ *such that* $\tilde{p} = \phi(\tilde{p}) + c$
2. *The expected profit is* $\Pi^* = (\tilde{p} - c)^2 S'(\tilde{p})$ *where* $\tilde{p}$ *is defined by* $\tilde{p} = \phi(\tilde{p}) + c$.
3. $\underline{p}$ *for firm 1 is defined by*

$$(\underline{p}_1 - c)\left[1 + \int_{\underline{p}_1}^{\overline{p}} S(p_2) f(p_2) \mathrm{d}p_2\right] = (\tilde{p} - c)^2 S'(\tilde{p})$$

.

Proof: See Appendix A.

Proposition 2 states that firms never charge a price greater than the price that maximizes profits from non-searching consumers. They may charge a lower price if there is some chance that they will attract searching consumers as well. However, they will not charge prices too close to marginal cost since they can always make a positive profit by selling to non-searching consumers only. The expected profit from the mixed strategy equilibrium will be equal to the maximum profits made by selling strictly to non-searching consumers.

Directly computing the lower bound of the mixed strategy, $F(p)$, defined in Proposition 2 requires one to derive the entire distribution of the mixed strategy. Fortunately, it is possible to significantly reduce the region of possible values of $\underline{p}$.

Lemma 4 *For every c, $\underline{p}$ satisfies:* $\underline{p} \geq (\overline{p} - c)\left(\frac{1-S(\overline{p})}{1+S(\overline{p})}\right) + c$.

Proof: See Appendix A.

The shaded region in Figure 2 represents the largest possible support of the equilibrium mixed strategy distribution. It is the interval between $\overline{p}$ and the lower bound specified in Lemma 4. The equilibrium strategy depicted in Figure 2 assumes uniformly distributed consumer search costs and normally distributed consumer priors on prices. A "no search" price and an "all search" price only exist when the support of the search cost distribution compact. Otherwise there is a mixed strategy equilibrium for all values of c. Appendix C calculates the resulting equilibrium for several different parameter values and different functional forms of the search cost distribution. The Gamma Distribution provides an example of a search cost distribution which produces a mixed strategy for all c.

The most important property of this model is that the equilibrium price increases with marginal cost, c, when c is high relative to consumers expectations of price, but the equilibrium price does not decrease with c when c is much lower than consumers expectations. This equilibrium property will be responsible for generating asymmetric price adjustment in the dynamic model developed in the next section.

Notice that while price search is the focus of the this model, price dispersion itself is not modeled. In fact, some equilibria have no price dispersion at all (the pure strategy equilibria). The motivation for the reference price search model is to explain changes in search activity related to overall movements in price level. To keep the model simple, it *assumes* the existence of price dispersion and consumer search. One interpretation is that there is an underlying price dispersion and uncertainty in this market that is left out of the model but that is responsible for the search activity being modeled. This is a simple way to capture the general uncertainty that consumers have about prices in the market. To the extent that price dispersion is generated in the model, it results from a mixed strategy equilibrium. A more detailed model involving (locational) product differentiation and firm specific random cost shocks would probably provide more tangible insights about the source of price uncertainty.

The model also simplifies consumer search behavior to a one step search decision. It is straitforward to incorporate a sequential search decision over a larger number of firms. Consumers can also be allowed to update their expectations about prices after each observation within a period. Neither of these assumptions significantly affect the model's basic predictions of price adjustment behavior. Updating allows expectations to move closer to the actual price distribution, but expectations will never equal actual prices as long as positive weight is placed on the distribution of priors.[12]

2.2 Dynamic Model and Asymmetric Adjustment

The previous section defines a static model of competition and consumer search for the case where consumers' expectations about prices differ from the actual distribution charged in the market. The results are general and no assumptions are made about how or why expectations are too high or too low. This section describes a specific type of dynamic model that can be created by assuming that the distribution of consumers' beliefs are formed from past information (*i.e.* past prices). In this model, past price levels (as well as current marginal costs) directly affect the current competitive price equilibrium. The key result is the asymmetric adjustment of prices to positive and negative changes in marginal cost.

The model is motivated by the limited information gasoline consumers have about the pricing environment. Many consumers are not aware of the wholesale costs of gasoline, nor can they costlessly observe all the current retail prices in the market. Consumers may decide whether the price they see at a station is "good" or "bad" based on how it compares to prices they have observed in the past.

[12] Rosenfield and Shapiro (1981) show that under fairly natural conditions, sequential search with recall (even with updating) results in a familiar reservation price optimal stopping rule similar to that of the basic reference price search model.

Consider a series of discrete time periods in which the homogeneous product search model described above is repeated.[13] When consumers' expectations are higher (lower) than actual prices, the static model predicts that fewer (more) consumers will search. Therefore, the motivation of the dynamic model is that if consumers expect prices to be similar to those observed in the past, they will search less when prices are falling and more when prices are rising. Consumers expectations can be represented by any continuous distribution which somehow captures information about prices in previous periods. One simple example is to assume that a consumer who observes p_1 in period t has a distribution of beliefs about p_2 such that

$$p_2 \sim \mathcal{N}(\overline{p}_{t-1}, \sigma^2)$$

where σ is identical in all periods and $\overline{p}_{t-1} = \frac{(p_1^{t-1}+p_2^{t-1})}{2}$ is the mean of last period's prices.[14] An increase in p_{t-1} corresponds to an upward shift in the distribution of the beliefs about p_2. Since the values p^{as} and p^{ns} represent percentiles of the distribution of the beliefs about p_2, they increase one for one as p_{t-1} increases (as long as the distribution of search costs is held constant). Therefore, I define $\alpha^- = p_{t-1} - p^{ns}$ as a constant which holds for all values of p_{t-1}. Similarly I define $\alpha^+ = p^{as} - p_{t-1}$.

Proposition 3

1. *If $c < p^{ns}$, all else equal it takes at least $\frac{p_{t-1}-c}{\alpha^-} - 1$ periods before $p \leq c + \alpha^-$.*
2. *If $c > p^{as}$, p responds immediately and completely to $p = c$.*

Proof: See Appendix A.

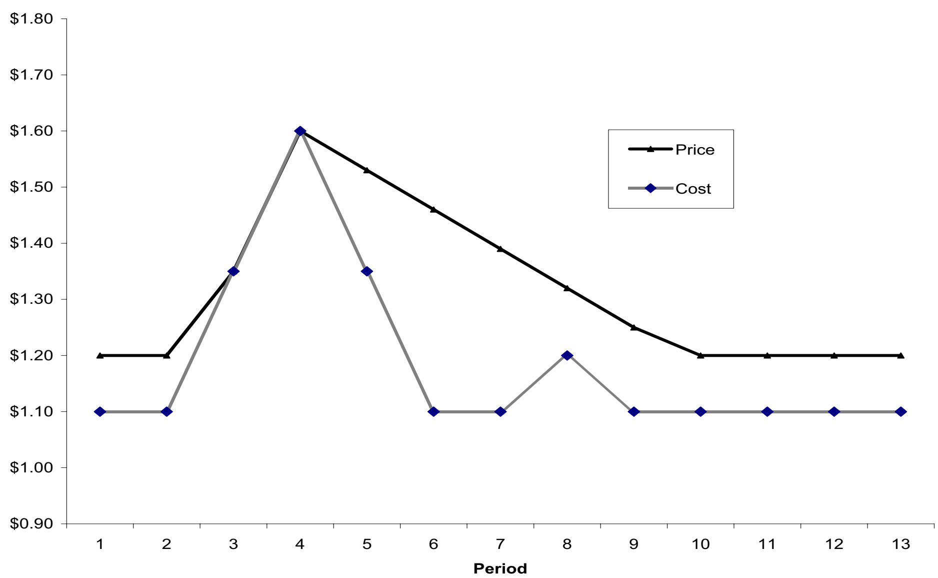
Proposition 3 implies asymmetric adjustment to changes in c. If c increases well above p_{t-1}, all consumers search and price adjusts immediately to c. However, if c falls well below p_{t-1},

[13] Firms are assumed to be myopic in the dynamic game so that they maximize current period profits as in the static game. This simplifying assumption eliminates the possibility that firms set prices to influence consumers' expectations (and therefore firm profits) in the future. The restriction is valid as long as there are enough firms in the market so that an individual firm cannot significantly affect the expectations of consumers. As stated in the previous section, the results of this model apply for any number of firms even though it is illustrated with just two.

[14] This could be viewed as a type of bounded rationality assumption, or alternatively a limited information assumption. Consumers are assumed to update their expectations of the level of prices, but they do not update, or do not have the information to update, their expectations about the shape of the distribution of prices in the market. It is only important that when prices are falling (rising) the distribution of consumers expectations is higher (lower) than it would be if they knew the true distribution of prices. A similar effect will result as long as expectations represent some function of the distribution of prices in the previous period (or periods).

no consumers search, price falls only by α^- each period and it may take several periods before price falls close to c. Once prices are significantly above costs ($p_{t-1} > c + \alpha^-$), increases or decreases in cost have no immediate effect on price. Price continues to decrease by α^- each period. The stylized example in Figure 3 shows these three phenomenon.

Figure 3: Stylized Example of Asymmetric Price Response to Changes in MC.



2.3 Summary of Theoretical Conclusions

Unlike previous search models, the reference price search model incorporates the idea that consumers' expectations of prices are based on equilibrium prices from the previous period. Lower expectations of price result in a higher perceived value of search for consumers. When consumer expectations are low relative to actual wholesale costs, more consumers search and profit margins are low. When expectations of price are high relative to wholesale cost, fewer consumers search and prices remain well above cost. These properties of search behavior result in asymmetric adjustment of prices to changes in marginal cost. When cost increases well above the price in the previous period, consumers search and prices immediately respond to the increase in cost. However, when cost falls well below the price in the previous period, prices fall just enough so that consumers will choose not to search. As a result, it can take a long time for prices to fully respond to a decrease in marginal cost.

The conclusions of the model are fairly robust to changes in specification. As presented, the model assumes that expectations are based on the previous period's prices. Very similar conclusions would result if expectations were based on the level of some weighted average of prices from several previous periods. A logical alternative to forming expectations from past price levels is to base expectations on the recent price trend. For example, the expected change in price this period might be the price change in the previous period. In this case, stations have to reduce prices at an increasing rate in order to keep consumers from searching. Once prices are falling, high margins are dissipated more quickly. However, prices in this model can "overshoot" cost spikes since rising prices are expected to keep rising. Prices still respond immediately to cost increases once consumers begin to search. An example of equilibrium price response of this model to the hypothetical cost shock in Figure 3 is illustrated in Appendix D. A more complex model could define expectations based on a mixture of past price levels and trends.

All of these specifications predict fairly rapid response once costs rise enough to encourage search, and slower, gradual response when cost falls well below expected prices. For the empirical analysis, I have chosen to base consumer expectations on the previous period's price level.

3 The Retail Gasoline Market: Description and Data

Gas stations sell a nearly homogeneous commodity. The marginal cost of a gallon of gasoline for all firms is roughly equal to the wholesale market price of gasoline. However the retail gasoline market is not a perfectly competitive homogeneous market. The travel costs and imperfect consumer information generate significant market power. Each station competes in a fairly localized submarket with most of its competition coming from neighboring stations. In addition, the gasoline sold at the retail stations is not perfectly homogeneous. Refining companies heavily advertise that the gasoline sold at their stations is superior. Most companies do add special additives to their gasoline just before it is sold to stations. Some consumers may be willing to pay more for certain brands of gasoline as a result of these differences.

It is fairly hard to observe all of the characteristics which might raise consumers willingness to pay at a particular station. Fortunately most of these "quality" characteristics, such as brand, location and station amenities, tend to be fairly constant over time. This will allow me to more easily control for these differences in the empirical analysis.

For the purposes of this study, I consider a firm to be a station which maximizes profits with marginal cost equal to the spot market price for gasoline. All types of stations can effectively be thought of as behaving in this way.[15] For an independent (unbranded) station the interpretation is straightforward. Station owners buy unbranded gasoline for their station at the wholesale market price and sell the gasoline at whatever price they choose. Alternatively, branded stations sell gasoline under a parent company's brand name. Some branded stations are owned and directly operated by the parent company. The parent company faces the same profit maximizing decision for each of these stations as an unbranded station would. Other branded stations are run by lessee-dealers who operate the station independently, but are required to buy gasoline from their parent company. The parent company determines the wholesale price which generally differs across stations within the brand. In addition, parent companies charge fees, set quantity requirements, and offer volume discounts for their lessee-dealers which also vary across stations. These parameters allow the parent company to very effectively extract most of the rents from their franchise stations. Therefore, the parent company maximizes profits for the station; effectively determining a retail price by setting the wholesale transfer price and franchise fees. If the parent company were not able to extract all these rents, double marginalization might be observed at lessee-dealer stations. However, evidence suggests little difference between the pricing behavior of company operated and lessee-dealer stations.[16] The lack of observed double marginalization suggests that all stations price as if profits were being maximized by a single firm given the wholesale cost of gasoline.

[15] In most cases "jobbers" are actually hired to deliver gasoline to the station, but this market is fairly competitive and the costs should not differ much across stations unless transport costs are significantly different. Within the single metropolitan area that I study these costs should be similar, but any differences will also be controlled for with station specific fixed effects.

[16] Hastings (2001) provides evidence that the organizational structure of a branded station (company operated vs. lessee-dealer) has no significant effect on the local market price. In addition, average margins in my dataset are only slightly higher (1.5 cents) at lessee-dealer than at company operated stations. This number is fairly small compared to overall margins which average around 16 cents. However, this figure is subject to the unobserved, systematic process by which a station is established as a company-op or lessee-dealer. Most importantly, during times when overall margins increased in my sample, margins at lessee-dealer stations did not increase significantly more rapidly than at company operated stations as one might expect if double marginalization was occuring only at lessee-dealer stations. This is even true for lessee-dealer stations with no nearby competitors (within a mile).

Although a large parent company might be maximizing profits for many stations, these stations are generally not located in the same area. Branded stations experience effectively no competition from other stations of the same brand.

Most previous work on asymmetric adjustment examined patterns in city average retail and wholesale price data. This paper utilizes station-specific retail price data to better describe observed behavior. Prices from approximately 420 gas stations in the San Diego area have been collected weekly from January 2000 to December 2001 by the Utility Consumer Action Network. Los Angeles "spot market" gasoline prices collected by the Department of Energy's Energy Information Agency are used as wholesale prices. This series represents the price of generic gasoline on the west coast and is calculated from a daily survey of major traders. Weekly wholesale prices are calculated as the average spot price over the week prior to each retail price observation. This is used as marginal cost because it is essentially the opportunity cost of keeping gas for your station instead of selling it to other wholesalers.

4 Empirical Analysis

The reference price search model identifies an important relationship between the size of profit margins and the speed in which prices respond to changes in wholesale cost. Therefore, it is informative to start this empirical examination by describing the size of profit margins relative to when prices are increasing or decreasing. I will look at the time series of city average prices and wholesale costs, defining profit margins as retail price minus wholesale cost.

Table 1 presents the average margins observed during periods when prices increased, when prices decreased, and when prices did not change substantially from the previous period. It is clear that margins are lower than normal in periods when prices are increasing and higher than normal in periods when prices are decreasing.[17] This behavior is clearly consistent with the predictions of the reference price search model where prices can only rise when the market is highly competitive.

[17] Table 1 reveals that profit margins are negatively correlated with the change in price despite the fact that price enters positively in the measure of margin ($p_t - c_t$). This relationship suggests that increases in price are often accompanied by even larger increases in cost.

Table 1: Average Profit Margins for Periods of Positive and Negative Changes in Price. (Cents/Gallon)

(N = 95 weeks)

	N	Average Profit Margin[a]
Periods with Large Positive[b] Price Change	22	4.81 (2.11)
Periods with Very Little Price Change	33	13.37 (1.97)
Periods with Large Negative Price Change	40	29.91 (2.23)

[a]Profit margin is $p_t - c_t$. Standard errors of means in parenthesis

[b]Periods are defined as having a large increase or decrease in price if price changed by more than one cent from the previous period.

4.1 Price Response to Cost Changes

Given that the direction of price movements appear to be empirically related to margin size, I would now like to examine whether the speed of price response is also sensitive to margin size. One of the most interesting predictions of the reference price search model is that equilibrium prices do not respond to changes in cost when profit margins are high. This contradicts the simple profit maximizing comparative static that higher costs should result in higher equilibrium prices. Instead, consumers decide not to search if they observe a price significantly lower than the previous week. Therefore, equilibrium prices only respond when cost is high enough so that firms charge a price above the "no-search" price.

It is helpful to illustrate two interesting patterns that result when prices respond less to cost changes while margins are high. These suggestions were made in section 2.2, during the discussion of the reference price model. The first is that this behavior can cause prices to adjust faster to cost increases than decreases. This is simply because cost increases are more likely to put the firm in a situation of low margins. Conversely, the firm is more likely to respond slowly after a cost decrease because it is more likely to have higher margins. This result parallels previous empirical literature on asymmetric adjustment which observes that prices respond faster to cost increases than decreases. However, the second interesting result is that firms respond less to cost increases when margins are high than when margins are low. This behavior has not been well studied because the dynamic models used in previous empirical studies (e.g. BCG (1997)) did not allow this type of asymmetry. The following empirical analysis suggests that the level of margins may have a more significant effect on response behavior than the direction of the cost change. I now discuss the empirical model used to test for the presence of these types of equilibrium price behavior.

4.1.1 Empirically Modeling the Dynamic Price-Cost Relationship

The starting point for this analysis is to econometrically model the dynamic processes which describe the relationship between retail and wholesale gasoline prices. The ultimate goal is to estimate how current and future prices respond to a change in cost. Therefore, I am interested in the expectation of price conditional on the current value of cost as well as past values of price and cost. The best linear predictor of this conditional expectation is simply the least squares fitted value of: [18]

$$p_t = \sum_{i=0}^{I} \tilde{\beta}_i c_{t-i} + \sum_{j=1}^{J} \tilde{\gamma}_j p_{t-j} + \epsilon_t. \tag{1}$$

The economic rational for including c_t in conditional expectation is that retailers in this market set their price with knowledge of the current wholesale price, and the belief that changing their retail price will not be enough to affect the wholesale price for the entire market. Due to the linearity of Equation 1, all changes in cost result in an identical change in the prediction of expected retail price. However, theory and past empirical evidence suggest that some type of non-linear predictor would be more appropriate for this market. My purpose for modeling the dynamic process is to test how closely the theoretical models predict price behavior. Therefore, I eventually relax the linearity of the estimation along the dimensions predicted in the theory.

I work with data from a panel of stations, so the model I estimate includes both station and time subscripts. Equilibrium prices are likely to differ across stations due to local market characteristics and station characteristics. To allow for variation across stations I include station

[18] This assumes that c_t is uncorrelated with ϵ_t. As I will discuss in the next section, this assumption could be relaxed and tested with an instrumental variables estimation. Of course, if p_t and c_t are cointegrated, as my analysis suggests, then OLS estimates would again be consistent for this particular specification.

fixed effects in the model. These control for differences in average price across stations due to locational convenience, brand image or any other differentiated characteristics. The model can now be specified as:

$$p_{st} = \sum_{i=0}^{I} \tilde{\beta}_i c_{t-i} + \sum_{j=1}^{J} \tilde{\gamma}_j p_{s,t-j} + \sum_{s=1}^{S} \ (\eta_s \text{STATION}_s) + \epsilon_{st}. \tag{2}$$

where:

$$\begin{aligned} E(\epsilon_{st}) = 0 \quad \text{and} \quad Cov(\epsilon_{st}, \epsilon_{\tilde{s}\tilde{t}}) \ &= \ \sigma_{s\tilde{s},t} \quad \text{if} \quad t = \tilde{t} \\ &= \ 0 \quad \text{if} \quad t \neq \tilde{t} \end{aligned}$$

$$\text{STATION}_s \ = \ \text{station fixed effects}$$

Note that correlation in the error term across stations within a week has been allowed. This accounts for unobserved time specific shocks that might affect more than one station.

Dickey-Fuller tests of price and cost cannot reject nonstationarity in my sample. Furthermore, an Augmented Dickey-Fuller type cointegration test based on Engle and Granger(1987) suggests that price and cost are cointegrated. As a result, the model in Equation (2) can not be estimated in its current form, since all the variables are nonstationary. However, Engle and Granger(1987) and Stock(1987) suggest estimation procedures for cointegrated autoregressions once they are transformed into an error correction form. This is obtained by simply subtracting $p_{s,t-1}$ from both sides of Equation 2 to produce: [19]

$$\begin{aligned} \Delta p_{st} \ &= \ \sum_{i=0}^{I-1} \beta_i \Delta c_{t-i} + \sum_{j=1}^{J-1} \gamma_j \Delta p_{s,t-j} + \\ & \quad \theta \left[p_{s,t-1} - \left(\phi c_{t-1} + \sum_{s=1}^{S} \ (\nu_s \text{STATION}_s) \right) \right] + \epsilon_{st} \end{aligned} \tag{3}$$

where:

$$\Delta p_{st} = p_{st} - p_{s,t-1} \quad \text{and} \quad \Delta c_t = c_t - c_{t-1}$$

Notice that the model has not been differenced. I have simply rearranged terms creating new coefficient parameters and leaving the error term unchanged. The variables remaining in levels have been

[19] To illustrate for the case where I=4 and J=3, the coefficients from Equation (3) map into those from Equation (2) as follows: $\beta_0 = \tilde{\beta}_0$, $\beta_1 = -(\tilde{\beta}_2 + \tilde{\beta}_3 + \tilde{\beta}_4)$, $\beta_2 = -(\tilde{\beta}_3 + \tilde{\beta}_4)$, $\beta_3 = -\tilde{\beta}_4$, $\gamma_1 = -(\tilde{\gamma}_2 + \tilde{\gamma}_3)$, $\gamma_2 = -\tilde{\gamma}_3$, $\theta = (\tilde{\gamma}_1 + \tilde{\gamma}_2 + \tilde{\gamma}_3 - 1)$, $\theta\phi = (\tilde{\beta}_1 + \tilde{\beta}_2 + \tilde{\beta}_3 + \tilde{\beta}_4 - \tilde{\beta}_0)$

collected into the form of an “error correction term”. This term represents the tendency for price to revert to its long run relationship. In particular, θ measures the percentage of per period price reversion to the station specific long run relationship specified by: $p_t = \phi c_t + \sum_{s=1}^{S} (\nu_s \text{STATION}_s)$.

Estimating a model of conditional expectation (such as in Equation (3)) gives a prediction of price conditional on cost and past values of price and cost. However, my analysis is focused on the effect a change in cost has on current and future prices. Therefore, I use the coefficient estimates to calculate *cumulative response functions* (CRFs). These CRFs predict the response path of price to a one unit change in cost. The predicted effect on price n periods after a cost change is a complex function that includes the direct effect of the past cost change (β_{t-n}), plus the indirect effects from the resulting price changes in the previous $n-1$ periods (γ_j's), and the error correction effect.[20] These CRFs allow observed response behavior to be easily compared with that predicted by the theoretical models.

4.1.2 Nonlinearities and Estimation Technique

The linear model above predicts identical responses to all changes in cost. I would like to test the theoretical implication that price is more responsive to cost changes when profit margins are low. Therefore, I relax the linearity assumption by allowing the coefficients to be estimated separately for periods of “high” and “low” margins. Response behavior can then be estimated separately for each regime, and tests can identify if these estimates significantly differ. This section discusses estimation techniques as well as methods for introducing these nonlinearities into the model.

The error correction form is often used when trying to estimate autoregressions with cointegrated variables. Fortunately, the error correction model also suggests a natural way to identify “high” and “low” margin periods. Since the long run relationship between p and c is an explicit term in the model, it can be used as a benchmark to determine “high” and “low” margin periods. Periods in which p_{t-1} is above its long run equilibrium level given c_{t-1} are designated as high margin periods.[21]

[20] CRFs are calculated by the method specified in the Appendix of BCG(1997)

[21] As a robustness check, I have estimate the model using a wide range of other values to split high and low margin periods. None of these estimates are qualitatively or statistically different from those presented in the paper. Theoretically, price behavior in the reference price search model depends on the relationship of p_{t-1} and c_t. Using this relationship to divide the sample also gave very similar results to the method used in the paper involving p_{t-1}

The error correction term of the model in Equation (3) contains levels of p_{t-1} and c_{t-1} which are non-stationary and cointegrated. As a result, Engle and Granger(1987) and Stock(1987) show that estimates of the parameters in the error correction term are superconsistent and produce misleading standard errors. While superconsistency prevents ordinary significance testing, it does provide good point estimates of the cointegrating relationship. Both studies suggest a simple, commonly used two stage estimation approach that takes advantage of this by superconsistently estimating the long run relationship between p and c implied in the error correction term as a first stage. This is simply the OLS estimation of:

$$p_{s,t} = \phi c_t + \sum_{s=1}^{S} (\nu_s \mathrm{STATION}_s) + \eta_{s,t}. \tag{4}$$

Again, station fixed affects capture each station's long run average profit margin. The lagged error term ($\eta_{s,t-1}$) from this regression can replace the error correction term in the estimation of Equation (3). Due to superconsistency the first stage residual ($\hat{\eta}_{s,t-1}$) can be used as the "true" value in the second stage and no standard error corrections are necessary.

The long run relationship is identified in the first stage, so the sample can be divided into high and low margin periods based on the sign of the lagged residual $\hat{\eta}_{s,t-1}$. Since the error from the first stage is estimated superconsistently, the selection is essentially based on a known parameter as opposed to an estimated one.[22] This is known as a threshold autoregressive model (see Enders and Granger(1998)).

The resulting model is:

$$\Delta p_{s,t} = \begin{cases} \sum_{i=0}^{I-1} \beta_i^{hm} \Delta c_{t-i} + \sum_{j=1}^{J-1} \gamma_j^{hm} \Delta p_{s,t-j} + \theta^{hm} \eta_{s,t-1} + \epsilon_t & : \quad \eta_{s,t-1} > 0 \\ \sum_{i=0}^{I-1} \beta_i^{lm} \Delta c_{t-i} + \sum_{j=1}^{J-1} \gamma_j^{lm} \Delta p_{s,t-j} + \theta^{lm} \eta_{s,t-1} + \epsilon_t & : \quad \eta_{s,t-1} < 0 \end{cases} \tag{5}$$

where $\eta_{s,t-1}$ is the error term from the OLS estimation of Equation (4).

and c_{t-1}. To correspond more closely with the theoretical motivation, price response is designated as occuring in a high or low margin period based on p_{t-1} and c_{t-1} in the period of the price change. However basing this designation on the margin in the period when the *cost* change occured does not significantly affect the estimates.

[22]As de Jong (2001) points out, estimation of models containing non-linear functions of the cointegrating vector has not been well studied. Although second step estimates will be consistent, de Jong's findings suggest that, in some cases, superconsistency is not enough to ensure correct standard errors. The use of panel data with a large cross-section in my study may help in achieving the proper asymptotic distribution.

Unfortunately, as Stock(1987) points out for the linear case, the first stage estimates from this procedure can be significantly biased in small samples. This is a result of estimating the long run relationship while ignoring short run dynamics. Stock(1987) also discusses a one step estimator which has similar asymptotic properties as the two step estimator and is likely to be less biased in small samples. This procedure simply involves OLS estimation of the error correction model (Equation (3)). Parameters of the cointegrating vector are still estimated superconsistently, but the rest of the parameters (including θ) have correct standard errors and can be thought of as being estimated independently of the cointegrating parameters.

To test the performance of these two estimators, I simulate results using data constructed to be of similar structure and sample size as my observed data. Appendix E discusses the simulations and presents the results. First stage estimates of the cointegrating coefficient (ϕ in Equation (4)) from the two step procedure commonly have a negative bias of up to 50%. Estimates of this coefficient using a one step estimation are much better, far out performing the two stage estimates for all sample lengths.

Suspicions of bias also arise when the two step estimator is used on the observed data. Theory would suggest that the long run equilibrium price relationship (Equation (4)) should have a coefficient on cost that is very near to 1. In this industry the cost of selling an additional gallon of gasoline is almost entirely made up of the wholesale price of gasoline, and there is no way to substitute some other input when costs increase. Previous empirical studies provide further support, having generally estimated this coefficient close to 1 as well (e.g. BCG (1997), Borenstein and Shepard (1996), Johnson (2002)). In contrast, the first stage of my estimation predicts $\phi = .48$, implying that price adjusts to only 48% of any cost change. This is most likely a result of negative bias due to the short sample period of just under two years and the volatility of prices during this period. Since p_t and c_t are cointegrated, ϕ can also be consistently estimated using a "reverse regression" of Equation 4 with c_t as the dependant variable. [23] In this case, the bias works in the

[23] The alternative estimate of ϕ would be $\frac{1}{\hat{\psi}}$ where $\hat{\psi}$ is the OLS estimate from the model:

$$c_t = \psi p_{s,t} + \sum_{s=1}^{S} (\lambda_s \text{STATION}_s) + \nu_{s,t}.$$

opposite direction resulting in an estimate of $\phi = 1.28$, suggesting that the true value of ϕ is, in fact, closer to one.

To avoid using these possibly biased estimates of the long run equilibrium, there are several alternatives to consider. One possibility is to restrict $\phi = 1$ based on theoretical reasoning. The error correction term would then represent the difference from the average retail margin $(p - c)$. Alternatively, I could use the one step estimator proposed by Stock(1987). However, by estimating in one step I can no longer use the first stage value of the error correction term to split the high and low margin periods prior to estimation. The estimates of the cointegrating vector are still superconsistent, so I could iteratively estimate using long run coefficients from the previous estimation to split the sample for the next estimation. A third alternative is to split the sample using some other exogenous cutoff. I continue to use the two step procedure with the restriction that $\phi = 1$. Results from the iterated one step procedure and the two step produce using the first stage estimate of ϕ are not presented here.[24] Estimates of response behavior using these methods are similar in speed of adjustment and level of asymmetry to those presented below. However, since they estimate ϕ to be different than one, the response functions tend to approach that estimated value of ϕ (instead of 1) which represents the long run relationship of p and c.

The beginning of Section 4.1.1 raised the issue of the possible endogeneity of the current period's cost in the price equation. All terms of the model in Equation 5 are stationary (unlike in Equation 2), so exogeneity of Δc_t in necessary to ensure consistent estimation the short run dynamics. The Δc_t may be correlated with η_t if unexpected retail price shocks in the current period could feed back into the wholesale price. Fortunately, I have good instruments available for wholesale gasoline prices. Crude oil prices are obviously highly correlated with gasoline prices. However, oil prices are largely determined in a worldwide oil market and many different products are produced from crude oil. For these reasons, changes in the price of gasoline in California are not likely to have much of an effect on world oil prices. Furthermore, changes in oil price should only affect retail gasoline prices through the wholesale gas price. Therefore, an oil price series such

[24]The estimate of the cost coefficient in the long run relationship using the one step estimator tends to be greater than one, $\phi \approx 1.5$. However, this is identified by dividing the OLS coefficient of c_{t-1} (superconsistent) by the OLS coefficient of p_{t-1} which implies a fairly large standard error, $\approx .29$.

as the West Texas Intermediate crude price provides an ideal instrument. [25]

Seven lags of cost and four lags of price are included in the estimation of Equation (5). These lag lengths are similar to those used in previous studies (1-2 months), and the estimates are fairly robust to changes in lag length specification.[26] To test for the exogeneity of cost in Equation (5), I estimate the model using instrumental variables and OLS. Robust standard errors are clustered by time period to remove the correlation of errors across stations within a week. Current and 3 periods of lagged West Texas crude oil prices changes are used as instruments for the current change in wholesale gasoline price. The first stage results of the IV estimation are reported in Appendix F, Table F1. Both a Hausman test and an augmented regression test are unable to reject the exogeneity of Δc_t above the 36% significance level. Therefore, my analysis will concentrate on the results of the OLS estimation.

The coefficients of Equation (5) are estimated separately for high margin ($\eta_{s,t-1} > 0$) and low margin ($\eta_{s,t-1} < 0$) periods. The behavior estimated by the high margin coefficients describes the response of p to a change in c given that p is above it's long run equilibrium level. Figure 4a presents the estimated CRFs during high and low margin periods. Recall that the CRF describes the cumulative proportional response of price in each period following a one unit change in cost in period t. The low margin CRF lies above the high margin CRF indicating that price responds more rapidly to a cost shock during a period of low margins than during a period of high margins. The CRF equals 1 when the cost change has been fully passed through to price. The low margin CRF approaches 1 much more quickly than the high margin CRF. Standard errors for these response functions are estimated using the delta method. The cumulative difference between these two response functions is also reported in Figure 4b and is significant until the sixth week following the shock. The cumulative difference at period n is the sum of the differences of the two CRFs over the previous n periods. This represents the total difference in price paid (cents/gallon) from

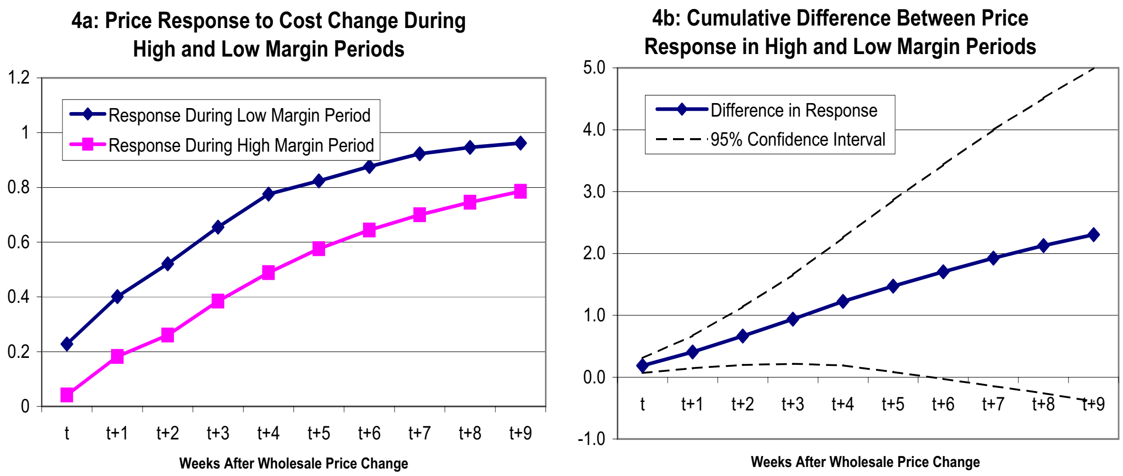
[25] I am implying the existence of a second equation in the model as follows (with r_t representing crude oil prices):

$$\Delta c_t = \sum_{i=0}^{I-1} \eta_i \Delta r_{t-i} + \sum_{j=1}^{J-1} \xi_j \Delta c_{t-j} + \lambda \left(c_{t-1} - \zeta r_{t-1} \right) + \nu_t.$$

If ν_t is correlated with ϵ_{st} from the price equation then IV would be necessary to estimate β_0 consistently.

[26] Additional lags continue to be significant when included (even for well above 10 lags), however additional lags sacrifice degrees of freedom and appear to have very little effect on the estimates of price response.

Figure 4: Cumulative Response Functions from Estimation of Equation 5



what would have been paid if price adjusted at the speed estimated in the other regime. For example, over the adjustment period a 10 cent increase in wholesale price during a low margin period would cost a 10 gallon/week consumer \$2.30 more than a 10 cent increase during a high margin period. The CRFs calculated from the IV estimation of Equation (5) are reported in Appendix F, Figure F1. These results are consistent with the prediction of the reference price search model. Prices are more responsive to cost when margins are low than when margins are high.

4.1.3 Refinements to the Nonlinear Structure

Unlike the analysis above, previous empirical studies of asymmetric adjustment have directly estimated separate price response functions for cost increases and decreases. Without considering margin size, these results generally indicate that price responds more rapidly to cost increases than cost decreases. The model in Equation (5) does not explicitly allow different price response behavior based on the direction of the cost change. Therefore, this section continues the above analysis while explicitly allowing for asymmetric response to positive and negative cost changes. This further relaxes the linearity of the estimation and helps to more accurately compare results with previous empirical findings and theoretical predictions.

The estimation of Equation (5) in the previous section assumes that price responds identically to all cost changes while p is above its long run equilibrium level. The CRF for a high margin cost change is estimated from both positive and negative cost changes occuring when price is above its long run equilibrium. If p responds differently to positive and negative cost changes within the high margin regime then the model in Equation (5) is misspecified.

To relax this assumption, separate coefficients can be estimated for positive and negative observations of each lagged cost and price change[27]:

$$\Delta p_{st} = \begin{cases} \sum_{i=0}^{I-1}(\beta_i^{+,hm}\Delta c_{t-i}^{+} + \beta_i^{-,hm}\Delta c_{t-i}^{-}) + \\ \qquad \sum_{j=1}^{J-1}(\gamma_j^{+,hm}\Delta p_{s,t-j}^{+} + \gamma_j^{-,hm}\Delta p_{s,t-j}^{-}) + \theta^{hm}\eta_{s,t-1} + \epsilon_{st} & : \quad \eta_{s,t-1} > 0 \\ \sum_{i=0}^{I-1}(\beta_i^{+,lm}\Delta c_{t-i}^{+} + \beta_i^{-,lm}\Delta c_{t-i}^{-}) + \\ \qquad \sum_{j=1}^{J-1}(\gamma_j^{+,lm}\Delta p_{s,t-j}^{+} + \gamma_j^{-,lm}\Delta p_{s,t-j}^{-}) + \theta^{lm}\eta_{s,t-1} + \epsilon_{st} & : \quad \eta_{s,t-1} < 0 \end{cases} \tag{6}$$

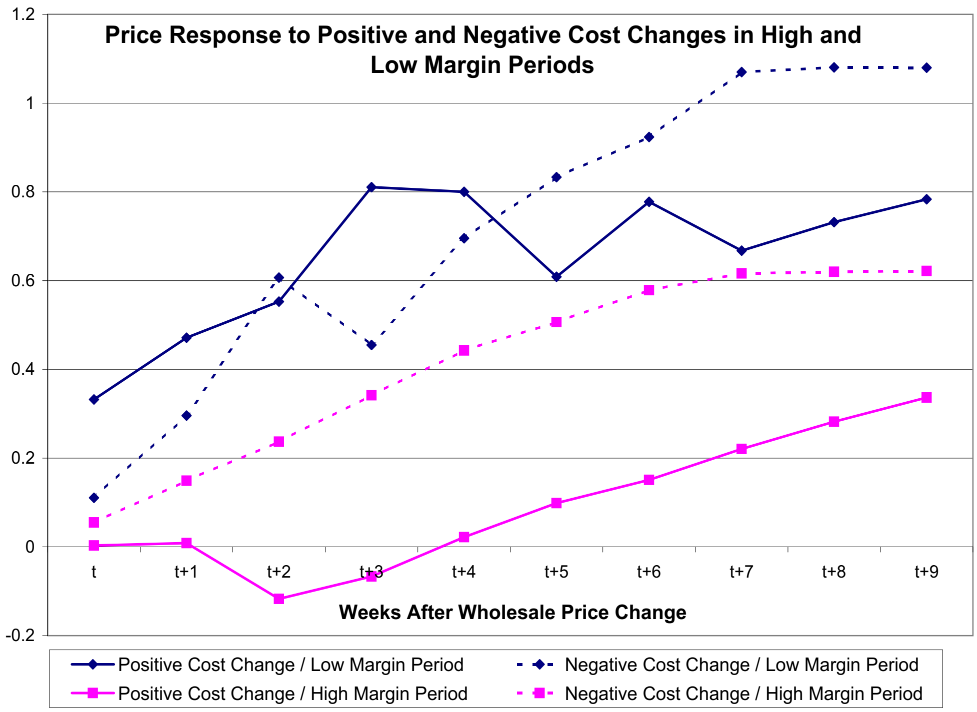
where $\eta_{s,t-1}$ is the residual from the OLS estimation of Equation (4).

Using this model, separate CRFs can be identified for positive or negative cost changes occuring during high or low margin periods. Equation (6) is estimated by OLS in the same manner as Equation (5). The resulting CRFs are reported in Figure 5. Once again, a Hausman exogeneity test of the current value of cost can not be rejected. Nevertheless, results of the corresponding IV estimation can be seen in Appendix F, Table F2 and Figure F2.

These results continue to suggest that prices respond more quickly in high margin periods than in low margin periods. The difference in the estimated speed of response during high and low margin periods to a positive cost change is even larger than the difference estimated in Figure 4 for a generic price change. In addition, the difference between high and low margin periods in the response to a negative cost change is only slightly smaller than the difference estimated in Figure 4 for a generic price change. This cumulative difference in response to a negative cost change is still significantly different from zero at the 90% level after the first 5 weeks following

[27] $\Delta c_{t-i}^{+} = \max(\Delta c_{t-i}, 0)$ and $\Delta c_{t-i}^{-} = \min(\Delta c_{t-i}, 0)$. Same for price change variables.

Figure 5: Cumulative Response Functions from Estimation of Equation 6



the cost change. A Wald test of the equivalence of the models in Equations (5) and (6) can be rejected at the 1% level, suggesting that estimating response behavior with separate coefficients for positive and negative cost changes is more accurate. In addition, Equation (6) allows for examination of response asymmetries between positive or negative changes within either high or low margin periods.

The previous empirical literature on asymmetric gasoline price adjustment has estimated more rapid responses functions to increases in cost than to decreases. However, these studies do not separately examine periods with high and low margins. My results suggest that, in fact, responses to positive cost changes appear faster only because positive cost changes tend to lead to periods of low margins. After controlling for the size of profit margins, I find no evidence that prices respond more quickly to increases in cost than to decreases. As the results in Figure 5 suggest, responses to positive and negative cost changes are not significantly different during low margin periods, and during high margin periods the responses to cost increases are actually slower than the responses to decreases. The level of profits being earned in the market seems to be a much stronger determinant of the speed of price response than the direction of the cost change. Previous empirical studies of asymmetric adjustment could not identify this result while assuming an identical response to all cost changes of the same sign.

The result also provides strong evidence for the reference price search model, that predicts that prices should be less responsive to cost changes when margins are high. This is particularly evident in the response to cost increases. Prices respond relatively quickly to increases in cost when margins are low, but respond very little to increases in cost when margins are high. In fact, the estimated response function to an increase in cost during a high margin period is not significantly different from zero until at least 7 weeks after the cost change.

4.2 Station Price Reductions

The patterns of price response identified above describe the average pricing behavior of all stations in the sample. However, if individual stations are behaving very differently, the price response at each station may not resemble that of the average. Therefore, I utilize the station specific data in my sample to describe how differently these stations are behaving. In the reference price search model, prices respond more slowly when margins are high, because consumers' expectations of prices are high. Firms are able to take advantage of this by pricing just below expectations to prevent search. If all firms have consumers who act in this way, then each firm's price adjustment behavior should be similar. This might not be the case if price movements were a result of more idiosyncratic forces, such as localized collusion and price wars.[28]

I examine the extremes of station price response behavior by constructing a time series of the highest and lowest prices observed in the sample each week. The reference price search model would predict the highest and lowest prices behaving roughly the same as the city average price since firms are all acting similarly. I use the 2nd percentile and the 98th percentile prices instead of the minimum and maximum prices to ensure that outliers do not drive the results.[29] Table 2 shows the correlation matrix of the "min" and "max" prices as well as the city mean price and wholesale cost.

[28]Such alternative explanations will be discussed in the following section.
[29]Using other percentiles close to zero and one do not substantially change the results in Table 2.

Table 2: Weekly City Min, Mean and Max Price Correlations
(N = 95 weeks)

Correlation Coefficients	Mean Price	Max Price	Min Price	Cost
Mean Price [a]	1.000			
Max Price	.9782	1.000		
Min Price	.9946	.9614	1.000	
Cost	.6324	.5917	.6704	1.000

[a]Max and Min prices are 98th and 2nd percentile prices respectively

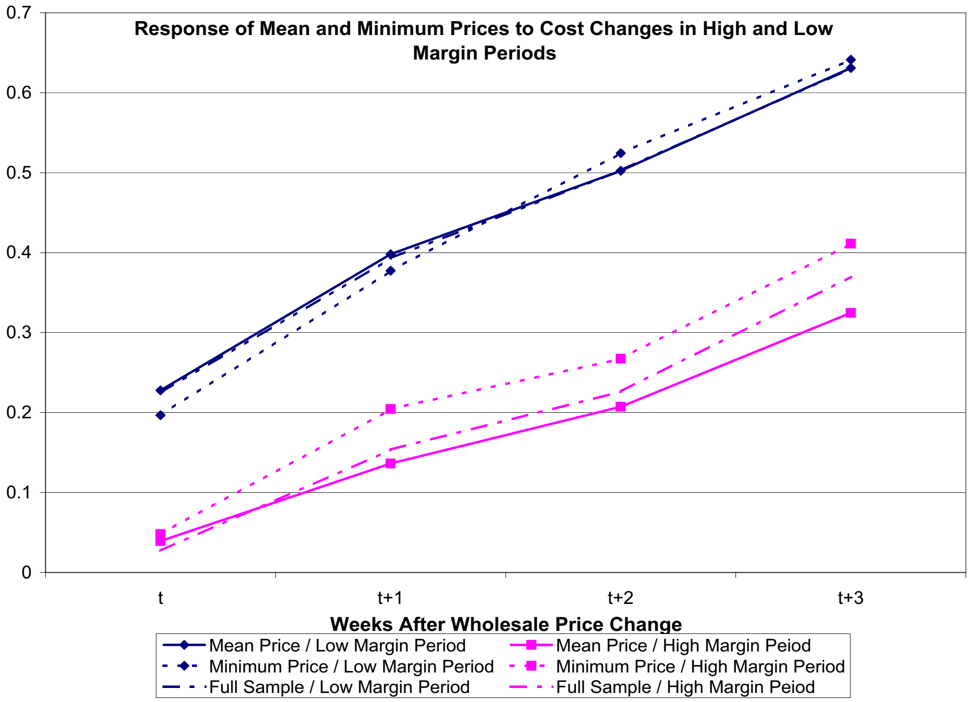
The minimum, maximum and mean prices for each week are much more highly correlated with each other than with the wholesale cost. The highest and lowest observed prices are adjusting to cost changes at about the same speed as the average prices, suggesting that all stations in the market respond to cost changes similarly, as the reference price search model predicts.

Relative price response behavior can be more carefully examined by estimating and comparing the cumulative response functions of the mean price and minimum price in the market to changes in wholesale cost. As in the previous section, I separately estimate price response in periods when the average profit margin is lower or higher than normal. CRFs are calculated by estimating the model in Equation (5). However, each of these CRFs must be estimated from a single time series instead of from a panel. For this reason it is not feasible to estimate as many lags in the error correction model as are estimated in Section 4.1.2. Instead I estimate the model with 3 lagged changes in cost and 2 lagged changes in price. The results are presented in Figure 6. I first estimate this new specification on the full panel of stations. By comparing with the results from Figure 4 it is clear that the abbreviated specification produces similar estimates of the CRF as the full specification.

When constructing the price series of the minimum market price for each week I am looking for stations which are pricing most competitively relative to their typical pricing relationship. This means I want stations which are pricing the greatest amount below their average price. Therefore, I select stations with the lowest de-meaned price as low price stations.[30] The estimated CRFs for the mean price and the minimum price are presented in Figure 6. As in Table 2, the 2nd percentile

[30]Here prices are de-meaned from the station's average price over all time periods as follows: $p_{st}^{adj} = p_{st} - \frac{1}{T}\sum_{t=1}^{T}\left(p_{st} - \frac{1}{S}\sum_{s=1}^{S} p_{st}\right)$

Figure 6: Minimum and Mean Price Response Function Estimates

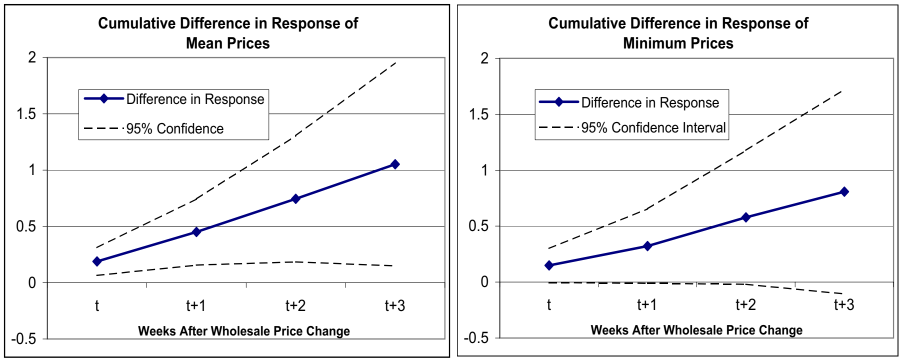


price is used instead of the minimum to avoid outliers.

The response functions confirm the results of the correlations in Table 2. It appears that the lowest prices in the market adjust to cost changes at roughly the same speed as the average station. The difference between estimated response functions in high and low margin periods is only slightly smaller for the minimum price than the mean price. Figure 7 shows the cumulative difference in response functions to changes in cost during high margin and low margin periods. The cumulative difference for the minimum price series is just on the borderline of significance at the 95 percentile. All stations appear to pass through cost changes at similar speeds, as they would if they were facing the marketwide demand conditions described in the reference price search model.

The empirical characteristics of price response behavior observed in these data appear to be consistent with the predictions of the reference price search model. In addition to the evidence provided here, the empirical findings of Deltas (2004) are also consistent with reference price search behavior. Deltas uses average gasoline prices to show that states with higher retail-to-wholesale margins tend to have retail prices that respond more asymmetrically to increases and decreases

Figure 7: Cumulative Difference in Response of Mean and Minimum Prices



in cost. This pattern is consistent with a reference price search model in which consumers' search costs vary by state. If search costs are high in a particular market then margins will be higher because fewer people will chose to search for a given price level (essentially making the market less competitive). High search costs also cause prices to fall more slowly since firms don't have to lower price as much each period to prevent consumers from searching. Therefore, high search costs lead to high margins and higher asymmetry of price adjustment, matching the behavior observed by Deltas (2004).

5 Alternative Explanations of Asymmetric Price Adjustment

The empirical evidence above suggests behavior consistent with the reference price search model. However there are other possible explanations for asymmetric price adjustment. This section compares the new empirical evidence of gasoline price adjustment behavior with the predictions of some previously suggested theories of asymmetric adjustment. A comparison reveals that predictions from these alternative theories appear to contradict some of the properties of actual pricing behavior observed in this market.

The general price theory literature provides very few possible alternative models of asymmetric adjustment.[31] Two possible alternative explanations of asymmetric adjustment were raised in an empirical examination of retail gasoline prices by Borenstein, Cameron & Gilbert's (1997),

[31] In menu cost models, such as Ball and Mankiw (1994), expected inflation causes firms to change prices more quickly in response to increases in cost than to decreases. However, these models do not apply in many markets, such as gasoline, where short term cost movements dwarf any long run inflationary trends.

henceforth BCG. The most frequently referenced theory identifies collusion as a possible source of asymmetry and temporarily high prices. A consistent ability to collude in a market produces higher price margins during all periods. However, if the ability to collude changes along with the marginal cost environment, this could produce asymmetric adjustment.[32] In the model proposed by BCG (1997), coordination is generally difficult, but firms are able to use past prices as a "focal price" at which to collude. When wholesale costs fall, collusion is easier to sustain because firms can coordinate by simply not changing their price. Decreases in cost provide an opportunity for competing firms to begin colluding. In contrast, firms would immediately raise prices in response to cost increases, since continuing to charge past prices would be unprofitable. Asymmetric adjustment results because collusion delays price reductions but not price increases.

Generally this behavior fits with the observed patterns of profit margins described in Table 1. Margins are lower when prices are increasing because collusion can not be sustained, and higher after costs fall because firms can temporarily collude. In addition, focal price collusion could explain the changes in the speed of price response that are observed in Figures 4 and 5. When prices are rising and the market is more competitive, prices will adjust to cost changes. However, if firms are colluding on past prices after costs fall, then fluctuations in cost are less likely to directly affect prices.[33] As in the reference price search model, prices will act more independently from cost during periods of high profit margins.

The type of asymmetric price adjustment resulting from focal price collusion is somewhat unique. If collusion breaks down simultaneously for all firms in the market, the average price would eventually fall very rapidly to competitive levels. This delayed, rapid fall in price is not commonly observed in gasoline markets.[34]. However, if smaller submarkets are colluding separately, then some prices in the market may fall before others producing a more gradual decline in the average market price.

Nevertheless, the price dynamics suggested by focal price collusion still differ from those

[32] Slade (1987) and Slade (1992) examine collusive activity and price wars among gas stations in the context of a dynamic game. Such fluctuations in collusion are not systematically related to movements in wholesale cost and, therefore, do not address asymmetric price adjustment.

[33] By definition, firms are colluding by keeping prices unchanged.

[34] See the gradual price declines in Figure 1

of the reference price search model. For average prices to decrease gradually, collusion must break down in a certain number of submarkets each period. Firms continue to charge the previous period's price until a shock causes collusion to breakdown in their area. As the average price is declining, a large number of firms charge either very high prices or very low prices. The highest prices in the city are the firms which are colluding at past prices. The lowest prices in the city are firms in locations where collusion has broken and prices are much more competitive. Therefore, the minimum price in the market should fall more quickly and adjust much more to changes in price, as they would in a competitive market. This prediction contradicts the behavior documented in Table 2 and Figure 6. The empirical evidence showed prices at even the highest and lowest priced stations in the market gradually declining in unison. Prices at low price stations behave much like the rest of the market. They are not more highly correlated with cost, nor do they respond more quickly to cost changes, as higher levels of competition would suggest. Station specific price response patterns clearly match better with the predictions of the reference price search model than with the focal price collusion theory.

BCG (1997) also suggest that consumer search behavior may affect price adjustment. They point out that a particular dynamic interpretation of the search model developed by Benabou and Gertner (1996) may be consistent with asymmetric adjustment. In this model increases in the volatility of wholesale costs can lower the value of consumer search. When uncertainty about wholesale cost increases, it becomes more difficult for consumers to determine if a change in price is unique to a particular firm or if it is a result of a market wide change in costs. Therefore consumers search less, and competitive profit levels increase. If higher cost volatility comes in the form of a cost increase, prices rise due to higher costs and also due to higher margins. For cost decreases, higher margins counteract the lower costs causing prices to fall less quickly. The result is asymmetric adjustment: prices tend to rise very fast and fall more slowly after changes in wholesale cost.

The Benabou and Gertner model has very different predictions about profit margins than the reference price search model and the focal price collusion theory. This model predicts higher profit margins during periods of uncertainty or volatility in wholesale costs. Asymmetric adjust-

Table 3: Correlations Between Margins and Measures of Cost Volatility
(N = 95 weeks)

	Profit Margin	5-week S.D. of Cost	3-week S.D. of Cost
Profit Margin	1.000		
5-week S.D. of Cost	.006	1.000	
3-week S.D. of Cost	-.187	.674	1.000

ment only results if periods of both increasing and decreasing prices and costs are accompanied by higher margins. In contrast, the focal price collusion model and the reference price search model result in asymmetric price adjustment by generating low (competitive) profit margins when prices are rising and high profits during other periods (since prices are "sticky" downward). The clear negative relationship between margin size and the direction of cost change from Table 1 suggests that observed behavior contradicts the Benabou and Gertner predictions.

The fundamental mechanism of the Benabou and Gertner explanation is that margins increase when wholesale cost become more volatile. This can be more directly tested using an empirical measure of cost volatility. One possibility is to measure this volatility by calculating the standard deviation of cost over the preceeding weeks. Correlations between margins and the three week and five week standard deviations of cost are reported in Table 3. The five week standard deviation of cost has virtually no relationship with margins, and the three week s.d. of cost has a small negative correlation with margins. Again, these statistics are opposite from the predictions of the Benabou & Gertner model. Together, the summary statistics reveal that the Benabou & Gertner model is unable to explain the periods of high profit margins in the data.

6 Discussion of Empirical Results

The empirical evidence in Section 4 suggests that the reference price search model predicts the type of price adjustments observed in retail gasoline. Section 5 discusses now other suggested explanations of asymmetric adjustment appear to be inconsistent with some of the empirical findings presented. Of course, this does not prove that the behavior described in the reference price search model is the cause of asymmetric adjustment. However, it identifies price patterns which appear inconsistent with other existing models of competition and consumer behavior. The empirical results clarify the necessary predictions of any model proposed to explain retail gasoline price asymmetries.

Any theory of asymmetric adjustment must predict that equilibrium prices are unresponsive to cost shocks when profit margins are high. This is not true for firms that individually maximize profits over a downward sloping residual demand curve. One possibility is that firms are colluding and therefore not individually profit maximizing. The other explanation is that the residual demand curve becomes very inelastic in a very particular way. This occurs in the reference price search model. The residual demand curve must become more inelastic below a certain price, and that price must change over time related to the past pricing environment. This property greatly limits the set of non-collusive models which could explain the asymmetric pricing behavior in retail gasoline.

The set of collusive models which could explain the observed behavior is also greatly restricted. There is no evidence in the data of groups of stations sharply decreasing price relative to the rest of the stations in the city. This suggests an absence of "breakdowns" in collusion in submarkets within the city. In fact, all stations seem to change prices in similar patterns with no evidence of deviation.[35] Therefore, a collusive equilibrium would have to be coordinated such that the collusive price falls gradually and is independent of changes in cost. Furthermore, there needs to be some reason why collusion is not possible when prices are rising.[36] It is hard to imagine why such a collusive strategy would arise within this (or any) market.

7 Conclusion

This paper analyzes the sources of asymmetric price adjustment in the retail gasoline market. It is one of the first attempts to carefully model the market behavior that leads to asymmetric adjustment. I develop a *reference price search model* of asymmetric adjustment in which searching consumers base expectations of current prices on prices observed in the previous period. The model

[35] Sharp price drops are also not observed for the city as a whole. So, even if one were to imagine the whole city maintaining a collusive equilibrium there is no evidence of a "breakdown" in collusion at this level.

[36] Alternatively, collusion might occur when prices are rising, but at a much lower level than after costs have fallen.

predicts that consumers search less when prices are falling, resulting in higher profit margins and very little price response to changes in marginal cost.

This is also the first paper to empirically compare and test the predictions of several theories of asymmetric adjustment with observed price response behavior. Analysis reveals that observed behavior is consistent with the predictions of the reference price search model. In addition, empirical estimates identify price behavior which is inconsistent with previously suggested theories of asymmetric adjustment. These results indicate that the type of search behavior described in the reference price search model is a possibly important source of asymmetric price adjustment in this market.

The reference price search model highlights an important inefficiency in this market. Incorrect consumer expectations can lead to periods in which prices are well above their full information competitive level. If all consumers were searching and were informed about the prices in the market, the reduction in equilibrium prices would be much larger than the sum of consumers' search costs. However, given that consumers have limited information, all firms charge higher prices and an individual consumer cannot significantly gain by searching to aquire price information. Data reveal the presence of this inefficiency. Even when retail prices are well above wholesale costs, there is little variation in prices across stations. Therefore, one consumer would not gain much by choosing to search, even though firms would significantly lower their prices if all consumers were searching.

Both the theoretical and empirical contributions of this paper should also help further the understanding of asymmetric price adjustment in other markets as well. While the reference price search model was motivated by search behavior in the gasoline market, it is general enough to apply to other goods with similar consumer search characteristics. More importantly, the empirical tests used to compare predictions of the theoretical models to observed behavior can also be used to help identify the causes of asymmetric adjustment in other markets.

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Appendix A: Proofs

Lemma 1 *$\Pi^{ns}(p)$ is uniquely maximized over the range $[p^{ns}, p^{as}]$ at* $\text{argmax}_p \Pi^{ns}(p) = \tilde{p}$ *such that* $\tilde{p} = \phi(\tilde{p}) + c$ *and* $\max_p \Pi^{ns}(p) = \frac{N}{2}(\tilde{p} - c)^2 S'(\tilde{p}) = \left(\frac{N}{2}\right) \frac{(1-S(\tilde{p}))^2}{S'(\tilde{p})}$.

Proof: For $p \in [p^{ns}, p^{as}]$, $\tilde{p} = \text{argmax}_p \Pi^{ns}(p)$ satisfies:

$$\frac{\mathrm{d}\Pi_1^{ns}}{\mathrm{d}p_1}(\tilde{p}) = \frac{N}{2}\left[-(\tilde{p} - c)S'(\tilde{p}) + (1 - S(\tilde{p}))\right] = 0$$

or more simply: $\tilde{p} = \phi(\tilde{p}) + c$. This solution is unique since $p - \phi(p)$ is a strictly increasing function (due to the monotone hazard rate assumption), and can only equal c at one value of p. The corresponding level of profit is:

$$\max_p \Pi^{ns}(p) = \frac{N}{2}(\tilde{p} - c)(1 - S(\tilde{p})) = \frac{N}{2}(\tilde{p} - c)^2 S'(\tilde{p}) = \left(\frac{N}{2}\right) \frac{(1 - S(\tilde{p}))^2}{S'(\tilde{p})}. \qquad \blacksquare$$

Lemma 2 *Values of p such that $p < p^{ns}$ are strictly dominated.*

Proof: Assume $p_1 < p^{ns}$. Then there exists some p^* such that $p_1 < p^* \le p^{ns}$ and $S(p_1) = S(p^*) = 0$. If $p_2 \le p^{ns}$ then $S(p_2) = 0$ and $x_1(p^*) = x_1(p_1) = \frac{N}{2}$. If $p_2 > p^{ns} \ge p^* > p_1$, then $x_1(p^*) = x_1(p_1) = \frac{N}{2}(1 + S(p_2))$. Therefore, for any value of p_2, it must be that p^* strictly dominates p_1. $\blacksquare$

Proposition 1 *The following properties of the pure strategy equilibria can be characterized:*

1. If $c \ge p^{as}$, all consumers search and $p_1 = p_2 = c$ is the unique equilibrium.

2. If $p^{ns} - \phi(p^{ns}) < c < p^{as}$, some consumers search and no pure strategy equilibrium exists.

3. If $c \le p^{ns} - \phi(p^{ns})$, no consumers search and $p_1 = p_2 = p^{ns}$ is the unique equilibrium.

Proof: Part 1: If $c \ge p^{as}$, all consumers search regardless of the price charged by the firms (given that firms never charge $p < c$). Full information Bertrand competition results in equilibrium prices $p_1 = p_2 = c$.

Part 2: Suppose $p_1 = p_2 > c$. By definition, $S(p) > 0$ for any $p < p^{as}$. So there exists an ϵ such that $c < p_1 - \epsilon < p_1$, where

$$\Pi(p_1 - \epsilon) = \Pi^{ns}(p_1 - \epsilon) + \Pi^s(p_1 - \epsilon) > \Pi^{ns}(p_1) + \frac{1}{2}\Pi^s(p_1) = \Pi(p_1).$$

Therefore $p_1 = p_2$ is not a best response to p_2.

Suppose $p_1 < p_2$. Then there exists a p^* such that $p_1 < p^* < p_2$. It is immediate that $x_1(p^*) = x_1(p_1)$ and, therefore, $\Pi_1(p^*) < \Pi(p_1)$. So $p_1 < p_2$ is not a best response to p_2.

Suppose $p_1 = p_2 = c$. Since $p_1 < p^{as}$ there exists some $p^* > p_1 = c$ such that $\Pi_1(p^*) = \Pi_1^{ns}(p^*) > \Pi(p_1) = 0$. So $p_1 = c$ is not a best response to $p_2 = c$. Hence, there is no pure strategy equilibrium for $c \in \Big(p^{ns} - \phi(p^{ns}), p^{as}\Big)$.

Part 3: Given that $p_2 = p^{ns}$, $S(p_2) = 0$. If $p_1 \geq p^{ns} = p_2$, then $\Pi_1 = \Pi_1^{ns}$. By Lemma 2, Firm 1 never charges $p_1 < p^{ns}$. Firm 1 charges $p_1 > p^{ns}$ only if

$$\frac{\mathrm{d}\Pi_1^{ns}}{\mathrm{d}p_1}(p^{ns}) > 0$$

which occurs when

$$c > p^{ns} - \phi(p^{ns}).$$

Therefore, when $c \leq p^{ns} - \phi(p^{ns})$, Firm 1's best response to $p_2 = p^{ns}$ is to charge $p_1 = p_2 = p^{ns}$. ■

Lemma 3 *For $c \in \left(p^{ns} - \phi(p^{ns}), p^{as}\right)$ an equilibrium mixed strategy must have expected profit $\Pi \geq (\tilde{p} - c)^2 S'(\tilde{p})$ where $\tilde{p}$ is defined by $\tilde{p} = \phi(\tilde{p}) + c$.*

Proof: Decompose expected profits into profits from non-searching and searching consumers: $\Pi = \Pi^{ns} + \Pi^s$. Non-search profits are simply $\Pi^{ns}(p) = \frac{N}{2}(p-c)(1-S(p))$. Consider the case when searching consumers never purchase from firm 1. Then firm 1's best response is $\tilde{p} = argmax_{p_1}(\Pi^{ns}(p_1))$. As shown in Lemma 1, this must satisfy $\tilde{p} = \phi(\tilde{p}) + c$. Therefore, a firm with $c \in (p^{ns} - \phi(p^{ns}), p^{as})$ is always able to make expected profit $\Pi(\tilde{p}) \geq \Pi^{ns}(\tilde{p}) = (\tilde{p} - c)^2 S'(\tilde{p}) = \frac{(1-S(\tilde{p}))^2}{S'(\tilde{p})}$. ■

Proposition 2 *For c in the range $\left(p^{ns} - \phi(p^{ns}), p^{as}\right)$ an equilibrium mixed strategy $F(p)$ over the support $[\underline{p}, \overline{p}]$ has the following properties:*

1. *$\overline{p} = \tilde{p}$ such that $\tilde{p} = \phi(\tilde{p}) + c$*
2. *The expected profit is $\Pi^* = (\tilde{p} - c)^2 S'(\tilde{p})$ where $\tilde{p}$ is defined by $\tilde{p} = \phi(\tilde{p}) + c$.*
3. *$\underline{p}$ for firm 1 is defined by*

$$(\underline{p}_1 - c)\left[1 + \int_{\underline{p}_1}^{\overline{p}} S(p_2) f(p_2) \mathrm{d}p_2\right] = (\tilde{p} - c)^2 S'(\tilde{p})$$

.

Proof: Part 1: With out loss of generality, assume there is an equilibrium pair of mixed strategies for the firms such that $\overline{p_1} \geq \overline{p_2} > \tilde{p}$. At $p_1 = \overline{p_1}$ no searching consumers purchase from firm 1. If $\overline{p_1} \geq p^{as}$ this results in $\Pi_1(\overline{p_1}) = 0$. This is a contradiction to Lemma 3. If $p^{as} > \overline{p_1} > \tilde{p}$, firm 1 makes some positive profit by selling to it's non-searching consumers. However, $\Pi(\overline{p_1}) < \Pi(\tilde{p})$ since $\overline{p_1} \neq \tilde{p} = argmax \Pi^{ns}(p)$. Thus, any $p > \tilde{p}$ violates Lemma 3 and can not be in the support of an equilibrium mixed strategy. Now assume there is an equilibrium pair of mixed strategies such that $\overline{p_2} < \overline{p_1} \leq \tilde{p}$. For $p_1 \geq \overline{p}_2$ no searching consumers purchase from firm 1. In this range of p_1, $\Pi_1(p_1) = \Pi^{ns}(p_1)$. For any $p_1 < \tilde{p}$, $\Pi_1(p_1)$ is less than $\Pi^{ns}(\tilde{p})$. This violates Lemma 3. Therefore, equilibrium strategies must satisfy $\overline{p}_1 = \overline{p}_2 = \tilde{p}$.

Part 2: Since Part 1 concludes that $\tilde{p}$ is in the support of an equilibrium mixed strategy, all values of p in the support must have expected profit equal to $\Pi(\tilde{p}) = (\tilde{p} - c)^2 S'(\tilde{p})$.

Part 3: In an equilibrium with $\underline{p}_1 = \underline{p}_2 = \underline{p}$, expected profit for firm 1 at $p_1 = \underline{p}$ is

$$\Pi_1(\underline{p}) = (\underline{p} - c)\left[1 + \int_{\underline{p}}^{\overline{p}} S(p_2) f(p_2) \mathrm{d}p_2\right].$$

Part 2 concludes that $\Pi(\underline{p}) = \Pi^*$. Therefore, $\underline{p}$ is implicitly defined by:

$$(\underline{p} - c)\left[1 + \int_{\underline{p}}^{\overline{p}} S(p_2) f(p_2) \mathrm{d}p_2\right] = (\tilde{p} - c)^2 S'(\tilde{p}). \quad \blacksquare$$

Lemma 4 *For every c, $\underline{p}$ satisfies:* $\underline{p} \geq (\overline{p} - c)\left(\frac{1-S(\overline{p})}{1+S(\overline{p})}\right) + c.$

Proof: Since $S(p)$ is an increasing function

$$\Pi_1(\underline{p}) = (\underline{p} - c)\left[1 + \int_{\underline{p}}^{\overline{p}} S(p_2) f(p_2) \mathrm{d}p_2\right] \leq (\underline{p} - c)[1 + S(\overline{p})].$$

Since $\overline{p}$ and $\underline{p}$ are both in the support of the equilibrium mixed strategy,

$$\Pi(\overline{p}) = (\overline{p} - c)(1 - S(\overline{p})) \leq (\underline{p} - c)(1 + S(\overline{p})).$$

Therefore,

$$\underline{p} \geq (\overline{p} - c)\left(\frac{1 - S(\overline{p})}{1 + S(\overline{p})}\right) + c. \quad \blacksquare$$

Proposition 3

1. *If $c < p^{ns}$, all else equal it takes at least $\frac{p_{t-1}-c}{\alpha^-} - 1$ periods before $p \leq c + \alpha^-$.*
2. *If $c > p^{as}$, p responds immediately and completely to $p = c$.*

Proof: 1. Lemma 2 concludes that price falls by α^- if $c \leq p_{t-1} - \alpha^-$. This repeats with p falling by α^- each period until $p \leq c + \alpha^-$.

2. This follows directly from Proposition 1 and the definition of α^+. $\blacksquare$

Appendix B: Reference Prices in the Marketing Literature

In this paper I develop model of consumer search that I refer to as the reference price search model. I use the term reference price simply to refer to the price consumers expect to find in the market. This is originally a marketing term which I adopt due to the conceptual similarities it shares with my model. In marketing literature, a reference price refers to a contextual benchmark price relative to which actual prices are judged. Typically these models assume that the difference between actual and relative prices has some direct effect on consumer utility. In other words, the utility consumers derive from a good can change based on their prior expectations of the price of the good.[37] This type of concept is not consistent with classical consumer theory in economics, which assumes that the utility of a good has no relationship to the price of the good. Nevertheless, there is a sizable theoretical and empirical marketing literature based on this concept.

Many of the empirical studies have found evidence consistent with the reference price theory. In particular, it has been estimated that the demand effects of seeing prices above the reference price are larger than the effects of seeing prices below the reference price. Studies have also found evidence suggesting that reference prices are often based on past prices. Kalyanaram & Winer (1995) give a nice overview of the existing empirical literature.

The consumer behavior which motivated the reference price search model developed in Section 2 is similar to that discussed in the marketing literature. However, the model does not rely on the reference price entering the consumers utility function. Instead, the reference price changes consumer behavior by affecting the perceived value of search. This provides an economically consistent theory of how reference prices can affect equilibrium firm sales and market prices.

[37] Putler (1992) gives a model describing how reference prices are incorporated into the consumer's utility function

Appendix C: Simulations of the Equilibrium Price Relationship

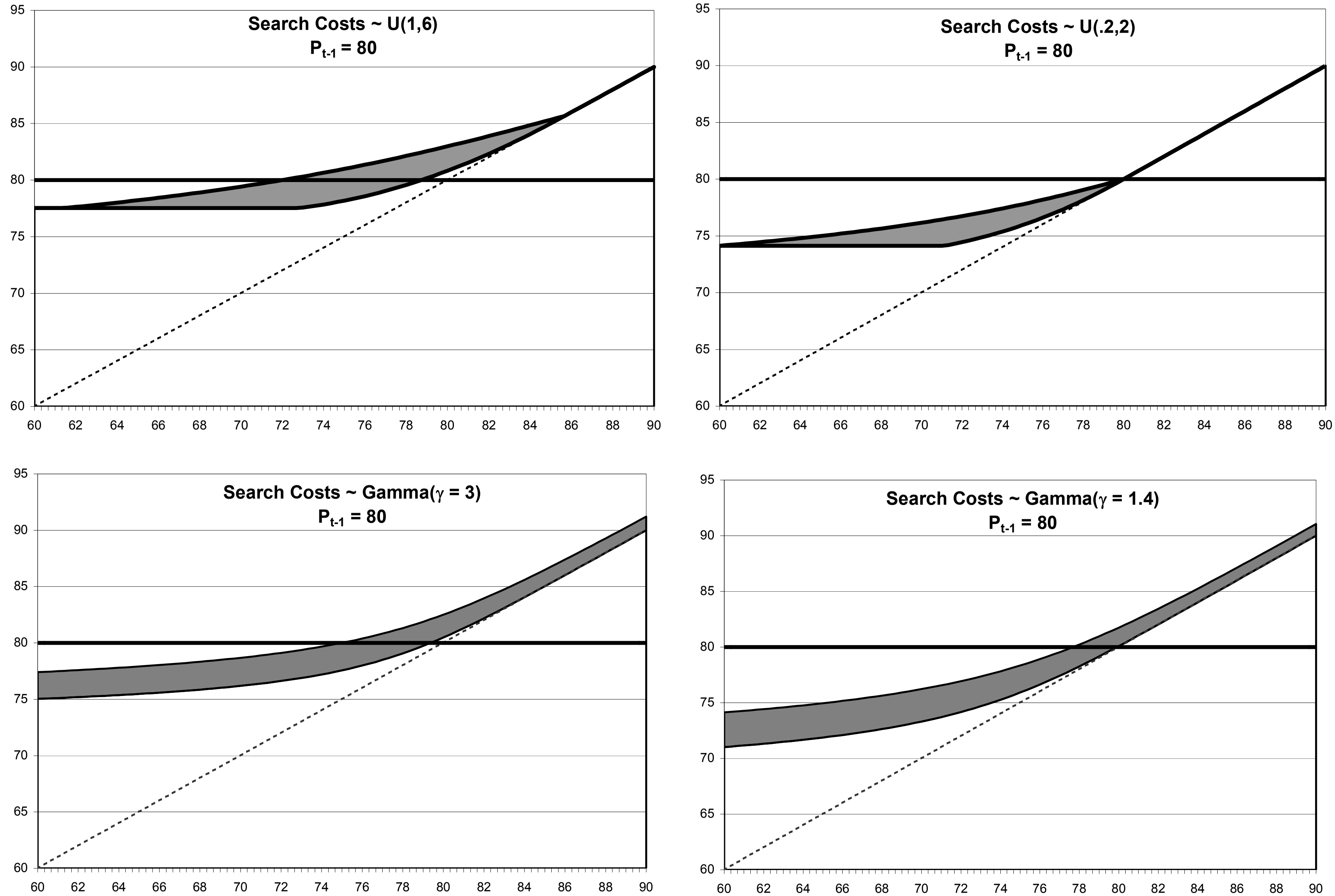
Section 2 does not solve for the explicit mixed strategy equilibrium relationship between price and marginal cost. Therefore, I have simulated the relationship under several different assumptions about the distribution of consumer search costs. The presentation in the paper describes a distribution of search costs which has finite support and an increasing hazard rate. The uniform distribution is a simple example of such a distribution. The endpoints of the uniform distribution result in the existence of an "all-search" price and a "no-search" price.

An equilibrium with a continuous distribution of search costs over an unbounded support has some consumers searching and some consumers not searching for all values of c. This results in a mixed strategy equilibrium for all values of c. I have used the Gamma distribution as an example of a continuous distribution that is bounded below by zero and has an increasing hazard rate.

Table C plots the bounds of the equilibrium mixed strategy price distributions for different values of marginal cost and a reference price $p_{t-1} = 80$. The parameters of the distributions are designated for each plot. Note that the Gamma distribution has a mean= γ. I have plotted a lower search cost and higher search cost equilibrium example for both type of distributions. Clearly a lower distribution of search costs lowers the equilibrium price relationship closer to the competitive price. Notice, for example, that a marginal cost equal to last period's price ($c = p_{t-1} = 80$) would result in a price fairly close to c in the low search cost case. In the high search cost case the equilibrium price is likely to be less competitive.

Table C: Equilibrium prices as a function of C

(for different search cost distributions)



"High" Search Cost Case **"Low" Search Cost Case**

Appendix D: Alternative Assumption of Consumer Expectations

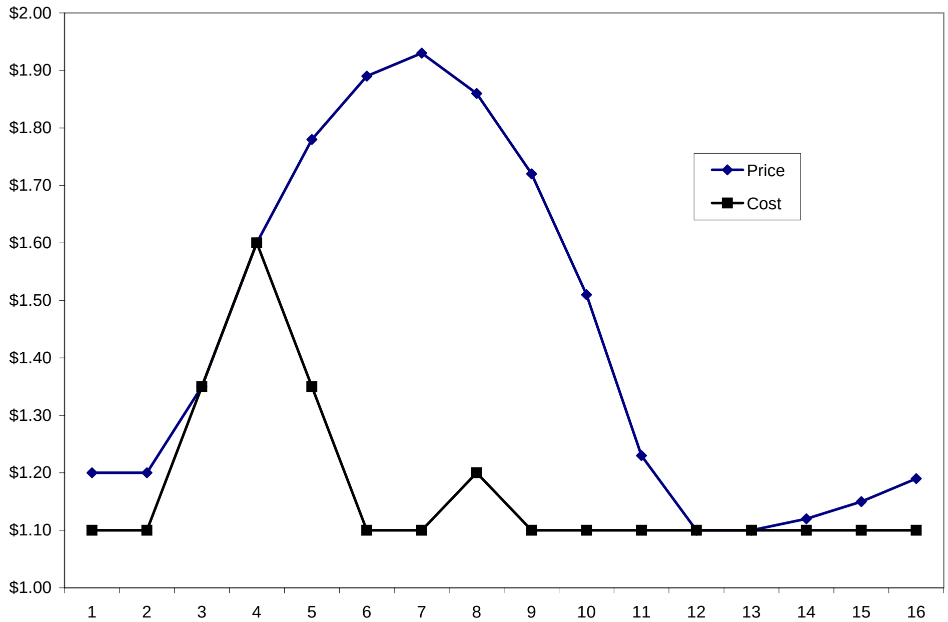


Figure D: Asymmetric price response to changes in MC.

Figure D presents an illustration of how equilibrium prices would respond to changes in wholesale cost under the assumption that consumer expectations are based on the previous period's price trend (instead of price level). Under this alternate assumption consumers expect the change in price this week to be equal to the change in price last week. In this model firms have to lower prices by an increasing amount each period in order to prevent search. However, prices may end up overshooting costs in the model. Once prices are increasing firms only have to increase prices at a slower rate to prevent search. As depicted in Figure D, a sudden spike in costs can quickly raise consumers expectations about the price trend. Once costs fall, prices can rise well above the peak cost level before expectations of the price trend finally become negative.

Appendix E: Simulations of One Step and Two Step Estimators

Stock (1987) and Engle & Granger (1987) both present methods for estimating error correction models with cointegrated variables. In addition to the identical two step procedures discussed in both papers, Stock (1987) proposes an alternative one step estimator. In section 4.1.2 I discuss the possibilities of bias in the estimation of the cointegrating vector of p and c using these procedures. Stock (1987) points out that estimates of the cointegrating vector from the one step estimator may have better small sample properties than corresponding estimates from the first stage of the two step estimator. The simulations in this appendix test the properties of both estimators on samples which are similar to that used in this paper.

The panel dataset used in this paper contains 95 weeks of price observations for each gasoline station. However, since I only observe one cost value each period, the simulations focus on a time series of prices and costs. I randomly generate artificial data sets which closely resemble the observed data. A time series of costs are generated as a random walk:

$$c_t = c_{t-1} + \eta_t \quad \text{where} \quad \eta_t \sim \mathcal{N}(0, 9),$$

since the weekly changes in cost observed in my sample have a variance of around 9 cents.[38] I create a corresponding series of prices by assuming a specific asymmetric error correction function which has coefficients similar to those observed in my estimation:

$$\Delta p_t = \begin{cases} \begin{aligned} &.15\Delta c_t^+ + .05\Delta c_t^- + .05\Delta c_{t-1} + \\ &\qquad .05\Delta c_{t-2} + .05\Delta c_{t-3} - .07(p_{t-1} - c_{t-1} - 10) + \epsilon_t \end{aligned} & : \quad p_{t-1} - c_{t-1} - 10 > 0 \\ \begin{aligned} &.35\Delta c_t^+ + .05\Delta c_t^- + .05\Delta c_{t-1} + \\ &\qquad .05\Delta c_{t-2} + .05\Delta c_{t-3} - .14(p_{t-1} - c_{t-1} - 10) + \epsilon_t \end{aligned} & : \quad p_{t-1} - c_{t-1} - 10 < 0 \end{cases} \tag{7}$$

Notice that c is assumed to have a coefficient of one in the cointegrating vector $p_{t-1} = c_{t-1} - 10$. I am interested in the small sample properties of this coefficient estimate.

In the two step estimation procedure, the cointegrating coefficient is the OLS estimate of ϕ in the first stage equation $p_1 = \alpha + \phi c_t + u_t$. Asymptotically this is a "superconsistent" estimate of the long run relationship between p and c. However, this estimate ignores the short run dynamics between p and c which are created by the error correction relationship. These short run dynamics can influence the estimates of the long run relationship when sample lengths are short.

The one step estimation procedure controls for these short run effects by including them in the equation to be estimated. The estimate of the cointegrating coefficient using the one step

[38] I drop the first 25,000 values of the series of costs generated in order to ensure that the initial value does not affect the simulation.

procedure is the OLS estimate of ϕ in the following equation:[39]

$$\Delta p_t = \beta_0^+ \Delta c_t^+ + \beta_0^- \Delta c_t^- + \beta_1 \Delta c_{t-1} + \beta_2 \Delta c_{t-2} + \beta_3 \Delta c_{t-3} + \theta(p_{t-1} - \phi c_{t-1} - \alpha) + u_t.$$

This estimate of ϕ also will be "superconsistent" due to the cointegration of p_{t-1} and c_{t-1}. However, it will be less biased due to the additional terms in the estimation.

I will use the simulated data above to test the small sample properties of these two estimates of the cointegrating coefficient. Artificial datasets of 100 periods, 300 periods, and 1000 periods are generated. Then ϕ is estimated using both the one step and two step procedures. I will repeat this simulation 1000 times. Table D presents the mean and standard deviation of the 1000 estimates for each procedure and sample size.

Table E: Summary of Cointegrating Coefficient Estimates from Simulations

(N = 1000 simulations)

	One Step Estimator			Two Step Estimator		
Sample Size	100	300	1000	100	300	1000
Mean	.969	.995	.999	.731	.891	.962
Std. Dev.	.225	.059	.018	.199	.091	.035

Increasing the sample length from 100 periods to 1000 periods clearly reduces the variance in the estimates of the cointegrating coefficient in both estimation procedures. For smaller sample lengths the estimates from the first stage of the two step estimator have a fairly large negative bias relative to the true value $\phi = 1$. For a sample length of 100 periods, it is not uncommon to see coefficient estimates as much as 50% below the true value. In contrast, the estimates from the one step procedure do not appear to be significantly biased even for sample lengths as short as 100 periods.

Since the sample length of the data used in this paper is 95 weeks, these results suggest that the estimate of the cointegrating vector from the two step procedure should probably not be used. Although the one step estimate may not systematically biased, it is estimated with a fairly large variance for samples of this length.

[39]The coefficient ϕ is identified from the OLS estimation as the coefficient of c_{t-1} divided by the coefficient of p_{t-1}.

Appendix F: Additional Results

Table F1: First Stage IV Estimates for Equation 5

Dependant Variable	Δc_t^{hm}	Δc_t^{lm}
Δoil_t^{hm}	2.461**	
	(.544)	
Δoil_t^{lm}		2.578**
		(1.063)
$\Delta\text{oil}_{t-1}^{hm}$	-.475	
	(.602)	
$\Delta\text{oil}_{t-1}^{lm}$		1.018
		(.972)
$\Delta\text{oil}_{t-2}^{hm}$	.416	
	(.665)	
$\Delta\text{oil}_{t-2}^{lm}$		2.905**
		(1.229)
$\Delta\text{oil}_{t-3}^{hm}$	.077	
	(.644)	
$\Delta\text{oil}_{t-3}^{lm}$		1.322
		(.903)
P(F-stat)^A	.0001	.0585
obs	27975	27975

Δoil_t represents the change in West Texas Crude Oil Price
Robust-Clustered standard errors are presented
Other exogenous variables not reported
^{A}F-stat is for joint significance test of instruments listed above
** Denotes significance at the 5% level, * 10% level

Table F2: First Stage IV Estimates for Equation 6

Dependant Variable	$\Delta c_t^{+,hm}$	$\Delta c_t^{-,hm}$	$\Delta c_t^{+,lm}$	$\Delta c_t^{-,lm}$
$\Delta \text{oil}_t^{+,hm}$	1.299	1.490*		
	(.799)	(.794)		
$\Delta \text{oil}_t^{+,lm}$			5.031**	-.067
			(1.839)	(1.014)
$\Delta \text{oil}_t^{-,hm}$	1.189**	2.438**		
	(.371)	(.602)		
$\Delta \text{oil}_t^{-,lm}$			-.126	2.035**
			(.861)	(.804)
$\Delta \text{oil}_{t-1}^{+,hm}$	-2.145**	-.615		
	(.588)	(.864)		
$\Delta \text{oil}_{t-1}^{+,lm}$			.424	.218
			(1.077)	(.980)
$\Delta \text{oil}_{t-1}^{-,hm}$	.087	-.201		
	(.307)	(.369)		
$\Delta \text{oil}_{t-1}^{-,lm}$			-.576	1.166
			(1.050)	(1.056)
$\Delta \text{oil}_{t-2}^{+,hm}$	-1.513*	-1.187		
	(.873)	(1.169)		
$\Delta \text{oil}_{t-2}^{+,lm}$			3.709**	2.883**
			(1.044)	(.781)
$\Delta \text{oil}_{t-2}^{-,hm}$	1.319**	.822		
	(.372)	(.514)		
$\Delta \text{oil}_{t-2}^{-,lm}$			-1.695	-2.051**
			(1.302)	(.971)
$\Delta \text{oil}_{t-3}^{+,hm}$	3.242**	2.353**		
	(.666)	(.818)		
$\Delta \text{oil}_{t-3}^{+,lm}$			.831	1.142
			(1.248)	(.670)
$\Delta \text{oil}_{t-3}^{-,hm}$	-.034	-1.245**		
	(.348)	(.503)		
$\Delta \text{oil}_{t-3}^{-,lm}$			.354	-1.219
			(.825)	(.974)
P(F-stat)^A	.0000	.0000	.0003	.0013
obs	27975	27975	27975	27975

Δoil_t represents the change in West Texas Crude Oil Price

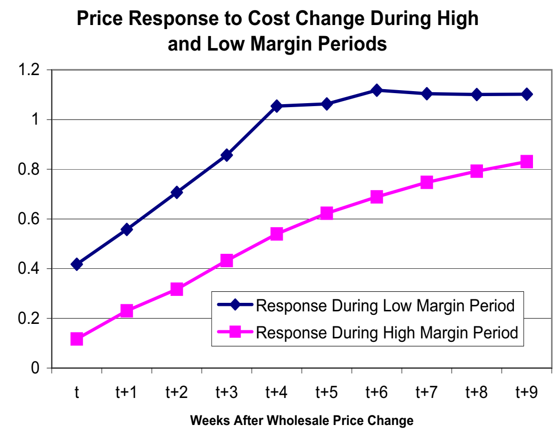
Robust-Clustered standard errors are presented

Other exogenous variables not reported

^{A}F-stat is for joint significance test of instruments listed above

** Denotes significance at the 5% level, * 10% level

Figure F1: Impulse Response Functions from IV Estimation of Equation 5



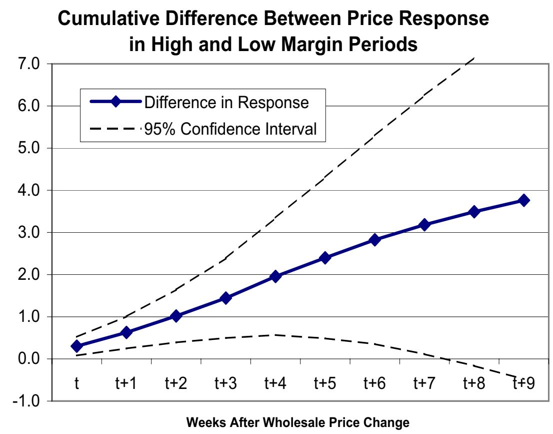


Figure F2: Impulse Response Functions from IV Estimation of Equation 6