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

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Abstract

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 and empirically tests how this and other existing theories match observed retail gasoline price behavior.

I develop a "reference price" consumer search model in which consumers' expectations of prices are based on prices observed during previous purchases. The model predicts that consumers search less when prices are falling. Reduced search results in higher profit margins and a slower response to cost changes than when prices are rising. My empirical findings support these predictions. I estimate the dynamic relationship between price and wholesale cost from a panel of gas station prices, and estimate the response pattern of price to a change in cost. The results identify periods of falling prices in which margins are high and there is little response to changes in cost. Furthermore, all stations behave similarly, and there is no evidence of collusive breakdowns or deviations. These findings are consistent with the predictions of the reference price search model and contradict some previously suggested explanations of asymmetric price adjustment.

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1 Introduction

The volatility of petroleum markets and the importance of gasoline to the world economy combine to draw interest from both the public and academics into the dynamics of retail gasoline prices. Specifically, the asymmetric adjustment of retail gasoline prices to increases and decreases in wholesale costs has drawn increasing attention over the last decade. A large empirical literature provides evidence that retail gasoline prices respond faster to cost increases than to cost decreases.[1] However, the previous research does not 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 theory of asymmetric adjustment and empirically tests how this and other previously suggested theories match observed retail gasoline price behavior.

Asymmetric price adjustment is not unique to the gasoline market. The phenomenon has been observed and studied in a variety of industries.[3] Although the model of asymmetric adjustment developed in this paper was inspired by the behavior of retail gasoline consumers, it is general enough to be applied to other industries with similar consumer search characteristics.

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 *reference price search model* includes searching consumers whose expectations of prices are based on prices observed during previous purchases.[4] If a consumer observes a price which is low relative to last periods price, he is less likely to search for a lower price. With fewer con-

[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), Finizza (2002).

[2] Eckert (2002) provides a theory of asymmetric adjustment and presents empirical support. However, the Edgeworth Cycle theory used by Eckert (2002) and Noel (2002) applies to 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. Johnson (2002) suggests a type of consumer search behavior similar to that of the model presented in this paper, but it is not formalized.

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

sumers searching, firms face more inelastic residual demand curves meaning less competition between firms and higher prices.

If marginal cost rises well above last period's price, firms are forced to charge high prices and all consumers choose to search. When all consumers search, the result is Bertrand competition and prices equal to marginal cost. If marginal cost falls well below last periods price, firms lower their prices just enough to prevent consumers from searching. When consumers don't search, firms can no longer attract more customers by lowering price. Firms maintain high margins as long as they continue to lower prices enough each period to prevent search. During high margin periods, the level of wholesale cost does not affect equilibrium prices. Firms price strictly to prevent search. As a result, 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 periods price. This usually happens following large increases in marginal cost. Price responds immediately to remain at or above marginal cost. When costs fall, margins increase and firms respond only by lowering price enough to prevent search. This partial response means that equilibrium prices adjust more slowly to negative cost changes than to positive cost changes.

One important assumption of this model 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.[5] 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, it is a very strong assumption that is hard to justify 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 were cost fluctuations produce rapidly changing price distributions. My model alters this assumption by limiting the amount of information consumers are assumed to have.[6] Consumers construct a perceived distribution of prices using price information from

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

[6] 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.

previous periods, and make search decisions accordingly. Both firms and consumers still behave optimally given this reduced information set. 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 asymmetrically to cost changes.

Borenstein, Cameron & Gilbert (1997), henceforth BCG, suggest two alternative explanations of asymmetric adjustment in retail gasoline prices. 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. 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, competing 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. If collusion breaks down simultaneously for all firms in the market, the average price would fall very rapidly to competitive levels. This is clearly not observed in the data. 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.

BCG (1997) also suggest that consumer search behavior may affect price adjustment. They point out that 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 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 empirical goal of this paper is to identify whether the predictions of the reference price search model and the other previously suggested theories are consistent with observed pricing behavior. While all suggest a form of asymmetric price adjustment, they differ in some more specific predictions regarding the dynamic behavior of equilibrium prices. The reference price search model predicts low margins while prices are rising and high margins while prices are falling. Alternatively, the Benabou and Gertner search model predicts high margins while prices are both rising and falling, since cost is volatile in both periods. In the reference price search model, asymmetric adjustment results from changes in consumer search behavior which affects all firms equally. Therefore, the model predicts that all stations reduce prices slowly and concurrently with other stations. High margins in the focal price collusion model are a result of firm specific collusive behavior, so it is likely that prices at some stations might decrease rapidly and independently of other stations. Such differences in behavioral predictions allow me to empirically test which model best fits the data.

Much of the empirical analysis relies on estimating the dynamic relationship between the retail price and wholesale cost of gasoline in this market. To do so, I model the expected retail price conditional on past values of price and wholesale cost. The estimation includes the particular nonlinear, asymmetric relationships predicted by the theoretical models. I utilize an adapted autoregressive model that allows the nonlinear and asymmetric relationships predicted by the theoretical models. Using 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, an error-correction form of the model is estimated using the techniques developed by Engle & Granger (1987) and Stock (1987). The coefficients are estimated separately for periods of high margins and low margins to allow for the differences in response behavior predicted in the reference price search model. Following 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. Tests are performed to identify significant differences in these response functions.

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. While these results are consistent with the predictions of the reference price search model presented in this paper, they contradict some of the implications of previously suggested theories. This indicates that the nature of price expectations and consumer search may be a very important source of asymmetric adjustment in this market.

These findings also challenge the existing empirical evidence on the response of retail gasoline prices to cost changes. Previous studies found that price responded faster to positive cost changes than negative cost changes. The results of this paper suggest that margin size may be a much more important determinant of the speed of price response. Controlling for the size of current margins, there is very 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.

The next section formalizes the details of the reference price search model. Sections 3 and 4 briefly discusses previous theories, and describes the structure of gasoline market. The empirical framework and results are presented in Section 5.

2 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 payed or observed in the past. Predictions regarding price dynamics are consistent with behavior observed in the data.

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. There are N consumers who each have unit demand for the good (up to a very high price). Each consumer expects to observe an exogenously determined distribution of prices, with continuous c.d.f. of $L(p)$ and p.d.f of $l(p)$ (which are identical for all consumers).[7] Consumers do not observe any information about marginal cost. 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:

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

[7] 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.

Assume that the distribution of search costs $G(k)$ has a compact support and satisfies the monotone hazard rate condition.[8] (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. There exists some price p^{ns} such that no consumers search ($S(p^{ns}) = 0$) , and some price p^{as} such that all consumers search ($S(p^{as}) = 1$).

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

[8]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.

choose firm 1, zero otherwise. The profit function for firm 1 is:

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

The specification of the profit function above only holds if firm 2 is playing a pure strategy. 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 for any p_1 is:

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

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:

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

The 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). The strategy of maximizing profits from non-search consumers becomes important as an alternative when competing for searching consumers becomes too costly.

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:

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

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:

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

The existence of p^{ns} represents 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.

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 $p_1 < p^* \leq p^{ns}$ and $S(p_1) = S(p^*) = 0$. If $p_2 \leq p^{ns}$ then $S(p_2) = 0$ and $x_1(p^*) = x_1(p_1) = \frac{N}{2}$. If $p_2 > p^{ns} \geq p^* > p_1$, 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. ■

2.1.1 Pure Strategy Equilibria

Given these results, it is now possible to describe the competitive equilibrium. The relative parameter values of c, p^{as}, and p^{ns} effect the nature of the equilibrium. Therefore, the equilibrium prices are described conditional on the value of c.

Proposition 1 *In the following cases, pure strategy equilibria can be defined:*

1. *If $c \geq p^{as}$, then $p_1 = p_2 = c$ is the unique equilibrium.*
2. *If $c \leq p^{ns} - \phi(p^{ns})$, then $p_1 = p_2 = p^{ns}$ is an equilibrium.*

Proof: Part 1: If $c \geq p^{as}$, 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: 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 $p_1 = p_2 = p^{ns}$. ■

For these values of c either all consumers are searching or no consumers are searching in equilibrium. If $c > p^{as}$, firms must charge $p > p^{as}$, and all consumers search. The outcome is identical to the conventional Bertrand equilibrium. 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. Firms have an incentive to slightly undercut other firms 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. (This, of course, is not a equilibrium because prices are now high and the incentive to undercut has returned.) This is similar to the mixed strategy equilibrium found in the informed/uniformed consumer model of Varian (1980).

Lemma 3 *For* $c \in \left(p^{ns} - \phi(p^{ns}), p^{as}\right)$ *no equilibrium pure strategy exists.*

Proof: 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 $c \in \left(p^{ns} - \phi(p^{ns}), p^{as}\right)$. ■

The equilibrium prices of the symmetric firms for each level of c are illustrated in Figure 1. The next section discusses the bounds of the support of the mixed strategy equilibria that are represented by the shaded portion of the graph. The example depicted most closely represents the case were the distribution of search costs, $G(k)$, is uniform and beliefs about the distribution of prices, $L(p)$, is normal.

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

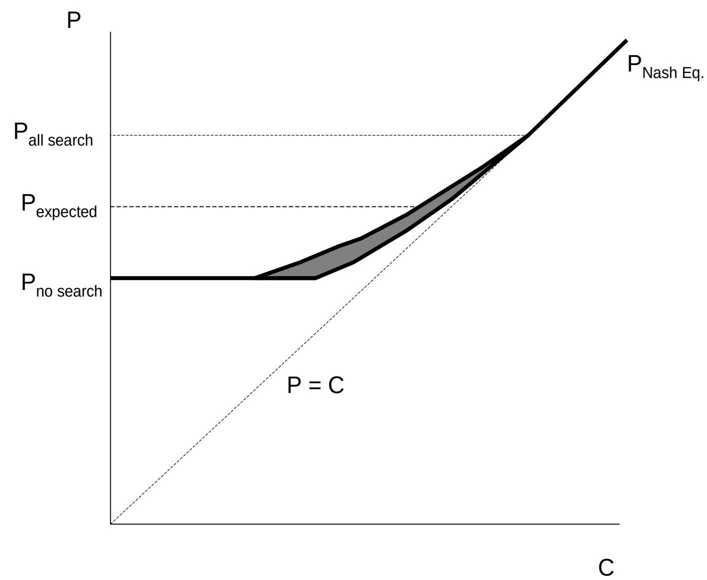


Figure 1: Nash equilibria prices for different states of C.

a price p such that $c < p < p^{as}$ and make positive profits by selling to non-searching consumers.

Lemma 4 *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: 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 $\Pi(\tilde{p}) \geq \Pi^{ns}(\tilde{p}) = (\tilde{p} - c)^2 S'(\tilde{p}) = \frac{(1-S(\tilde{p}))^2}{S'(\tilde{p})}$. ■

I do not fully derive the distribution of the equilibrium mixed strategy, but I can 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: 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 4. 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 4 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 4. 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:

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

It is straitforward to compute the upper bound of $F(p)$ using the implicit function in Prop. 2. However, computing the lower bound of $F(p)$ defined in Prop. 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 5 *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,

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

The shaded region in Figure 1 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 5. The equilibrium strategy depicted in Figure 1 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.

2.2 Dynamic Model and Asymmetric Adjustment

In the previous section I defined a consumer search model in which expectations about prices are based on an exogenous distribution. A dynamic model can be created by assuming that this distribution of beliefs is 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. This section presents this dynamic model and shows how it can produce asymmetric adjustment of prices to positive and negative marginal cost changes.

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 observed last period.

Consider a series of discrete time periods in which the 2 firm, homogeneous product search model described above is repeated. Define the mean of the consumers' distribution of beliefs about prices to be the average price charged in the market last period. Consumers decide whether to search or not by comparing the initial price they observe with their distribution of beliefs. Most consumers will not search if they observe a price that is low relative to last period's prices, since they believe there is little chance of finding a better price. Consumers are more likely to search after observing a price which is high relative to last period's prices.

The mean of last period's prices is: $p_{t-1} = \frac{(p_1^{t-1}+p_2^{t-1})}{2}$. Assume a consumer who observes p_1 in period t has a distribution of beliefs about p_2 such that

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

where σ is identical in all periods. 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: 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^+. ■

Proposition 3 implies asymmetric adjustment to changes in c. If c increases well above p_{t-1}, price adjusts immediately to c. However, if c falls well below p_{t-1}, 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 2 shows these three phenomenon.

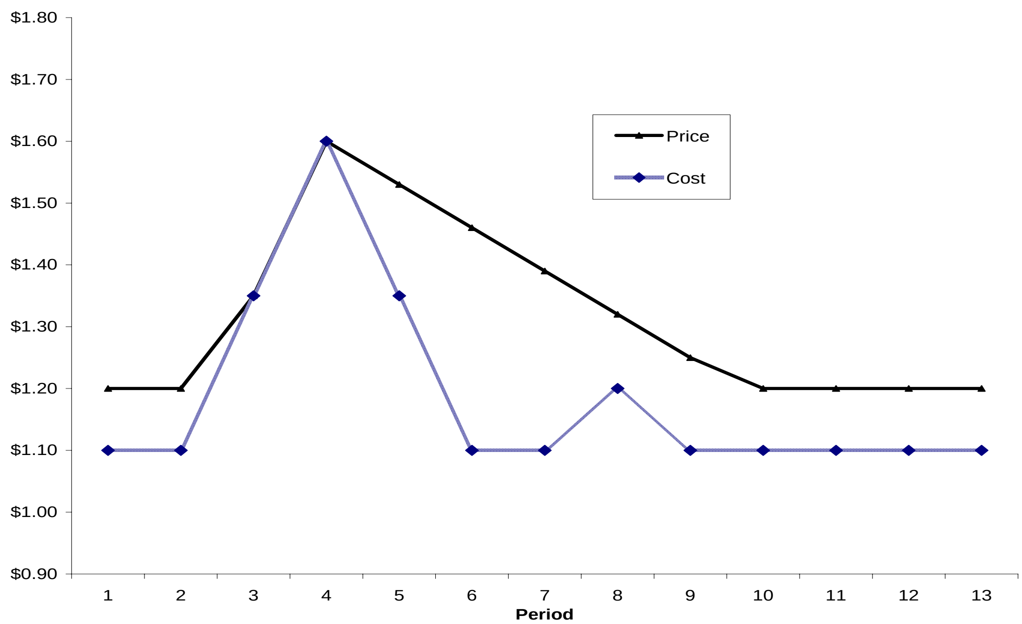


Figure 2: Asymmetric price response to changes in MC.

2.3 Conclusions and Robustness of the Model

The key mechanism of the reference price search model is that lower expectations of price result in a lower value of search for consumers. When consumer expectations are low relative to actual costs, less consumers search and profit margins are higher. Whenever price expectations change relative to costs, the speed at which price responds to cost will also change.

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 Table 2 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.

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.[9] 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

[9] 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.

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 and set quantity requirements for lessee-dealers which are defined in the franchise contract. 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.[10] 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. 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.

[10] Hastings (2001) provides evidence that the organizational structure of a station (company operated vs. lessee-dealer) has no significant effect on the local market price. In addition, average margins in my dataset differ only slightly (1.5 cents) between company operated and lessee-dealer 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.

4 Testable Implications and Empirical Results

The reference price search model as well as the focal price collusion model and the Benabou & Gertner search model discussed in BCG (1997) all generate asymmetric price adjustment in slightly different ways. As a result, each model has predictions about equilibrium price behavior that are distinct from the other models. These differences allow me to empirically test whether some of these theoretical models are more consistent with actual price response behavior. I will focus on three properties of price response behavior that can be identified using the available data and compared to the predictions of the models. The tests will address the following three questions:

1. When are high profit margins observed?

2. How quickly do prices respond to cost changes during periods of high margins?

3. How rapidly do individual station prices decline and do station prices decline in unison or at different times?

Each of the theoretical models have different sets of implications regarding these three questions. Identifying the theory which best fits observed behavior relies on understanding the predictions of each model. These predictions are presented and explained below:

Predictions of the Reference Price Search Model

1. **Profit margins are larger during periods of decreasing prices.**
   When prices are falling, consumers do not search and profit margins can be large. When prices increase, consumers search and competition reduces profit margins.

2. **Prices do not respond to cost changes during periods of high margins.**
   When margins are high, all firms lower prices just enough each period to discourage search. Changes in cost should not effect prices as long as price remains well above marginal cost.

3. **Individual station prices fall gradually and in unison.**
   Prices fall slowly since firms only reduce price enough to discourage search. Prices

at all firms should fall together and at the same speed since all firms face the same demand conditions.

Predictions of the Benabou & Gertner Search Model

1. **Profit margins are large during periods of increasing and decreasing prices.**
   High margins in the Benabou & Gertner search model result when increased cost volatility lowers the value of search for consumers. Asymmetric adjustment results if margins increase while costs are rising and falling. Prices will rise faster than costs because costs and profit margins are increasing simultaneously. Prices will fall slower than costs because profit margins are increasing while costs is falling. This contrasts the reference price search model, which predicts lower margins while costs are rising.

2. **Prices respond to cost changes during periods of high margins.**
   Firms in this model are always facing competition from other firms, so changes in cost will affect the profit maximizing prices of all firms. This does not occur in the reference price search model since residual demand becomes inelastic below the no search price.

3. **Individual station prices fall gradually and in unison.**
   Prices fall gradually with cost but are delayed by the temporary increase in margins due to reduced consumer search. Prices at all firms should fall together and at the same speed since all firms face the same demand conditions.

Predictions of the Focal Price Collusion Model

1. **Profit margins are large during periods of decreasing prices.**
   High margins result from collusion in this model. Since it is assumed that collusion is only possible once costs fall below past levels, high margins should exist when costs are falling. Margins should be smaller when costs and prices are rising and the market is competitive.

2. **Prices do not respond to cost changes during periods of high margins.**
   In this model firms collude by not changing price after costs fall. Changes to cost during periods of collusion and high margins will not affect price unless they cause collusion to breakdown.

3. **Individual station prices fall rapidly and at different times than stations in other submarkets.**
   Prices will only fall as a result of a breakdown in collusion. If all stations moved from collusive equilibrium to competitive equilibrium at the same time city average prices would fall very rapidly. This is clearly not observed in the data. However, if small submarkets of stations collude separately and break down at different times then average prices would fall more gradually. In this case, individual station prices should fall quickly but at different times throughout the sample.

Predictions of the three theories of asymmetric adjustment clearly have different predictions about equilibrium price behavior. Table 1 summarizes the predictions of the three models for each of the three testable implications discussed above. The empirical work in the rest of this section reveals how observed behavior matches these predictions.

The first subsection addresses the first testable implication by presenting summary statistics which illustrate when high margin periods occur. To addresses the second implication, the second subsection more carefully models and estimates the response behavior of price to changes in cost. The estimates are used to determine if response to cost changes are different during periods of high margins. The third subsection uses prices from specific stations to address the third implication regarding relative response behavior among firms.

4.1 Profit Margins

The first testable implication refers to the nature of periods with high margins. The Benabou & Gertner model predicts higher profit margins during periods of uncertainty or volatility in wholesale costs. This means both periods of increasing and decreasing prices and costs should be correlated with higher margins. In contrast, the focal price collusion model and the reference price search model predict low (competitive) profit margins when prices are

Table 1: Predictions of Theoretical Models for Empirical Tests

Empirical Tests	Benabou & Gertner Search Model	Focal Price Collusion Model	Reference Price Search Model
When are profit margins high?	When prices are rising and falling	When prices are falling	When prices are falling
When do prices respond to cost changes?	At all times	Only when margins are low	Only when margins are low
How and when do stations reduce prices?	Gradually and in unison	Suddenly and at different times	Gradually and in unison

rising and high profits during other periods (since prices are "sticky" downward).

Summary statistics help determine when high margins are observed in the data. The statistics describe the time series of city average prices and wholesale costs. First I identify if high margins are more frequently observed during periods of increasing or decreasing prices. Table 2 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. This behavior is clearly consistent with the predictions of the reference price search model and the focal price collusion model where prices can only rise when the market is highly competitive. However, it contradicts the Benabou & Gertner model which predicts higher margins when prices and costs are increasing and decreasing than when prices and costs are fairly stable.

I also test to see if direct measures of cost volatility are correlated with high margins. Volatility is measured 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 inconsistent with the data in regard to the first testable implication.

Table 2: 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]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.

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

4.2 Response to Cost Changes

The second theoretical implication that I test involves the relative response of prices to marginal costs during periods of high and low margins. In this subsection I empirically estimate the response behavior of prices to cost changes and compare the results to the predictions of the theoretical models.

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.

Prices in the focal price collusion model may also act independently from cost during periods of high profit margins. Firms continue to charge the same price as last period as long as collusion holds and margins are high. Once collusion breaks down firms have lower profit margins and react more to changes in cost.

In the Benabou & Gertner model, as well as most other models of competition, prices respond to cost changes in all periods. Therefore, finding an empirical relationship between margins and responsiveness to cost would generate strong evidence for the first two models.

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 did not allow this type of asymmetry. I now discuss the empirical model used to test for the presence of these types of equilibrium price behavior.

4.2.1 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: [11]

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

[11]This assumes that c_t is uncorrelated with ϵ_t. In that case, instrumental variables estimation can be used to produce unbiased estimates. I will discuss the possibility of endogeneity in the next section.

However, due to linearity, all changes in cost result in an identical change in the prediction of expected retail price. 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 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:

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

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: [12]

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

where:

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

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 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: $p_t = \phi c_t + \sum_{s=1}^{S} \ (\nu_s \mathrm{STATION}_s)$.

Estimating a model of conditional expectation (such as in Equation eq:ec) 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 effects of the resulting price changes in the previous $n-1$ periods and the error correction effect. These CRFs allow observed response behavior to be easily compared with that predicted by the theoretical models.

4.2.2 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

[12]For the case where I=4 and J=3, the coefficients from equation (2) map into those from equation (1) as follows: $\beta_0 = \tilde{\beta}_0, \quad \beta_1 = -(\tilde{\beta}_2 + \tilde{\beta}_3 + \tilde{\beta}_4), \quad \beta_2 = -(\tilde{\beta}_3 + \tilde{\beta}_4), \quad \beta_3 = -\tilde{\beta}_4, \quad \gamma_1 = -(\tilde{\gamma}_2 + \tilde{\gamma}_3), \quad \gamma_2 = -\tilde{\gamma}_3, \quad \theta\phi_1 = (\tilde{\gamma}_1 + \tilde{\gamma}_2 + \tilde{\gamma}_3 - 1), \quad \theta = (\tilde{\beta}_1 + \tilde{\beta}_2 + \tilde{\beta}_3 + \tilde{\beta}_4 - \tilde{\beta}_0)$

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.[13]

The error correction term of the model in Equation 4 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:

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

The lagged residual ($\eta_{s,t-1}$) from this regression is then used in place of the error correction term in the estimation of Equation 4. Due to superconsistency the first stage residual 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 $\eta_{s,t-1}$. Since the residual from the first stage is estimated superconsistently, the selection is essentially based on a known parameter as opposed to an estimated one. This is known as a threshold autoregressive model (see Enders and Granger(1998)).

[13] As a robustness check, I have estimated the model using a wide range of other values to split high and low margin periods. None of these estimates were qualitatively or statistically different from those presented in the paper.

The resulting model is:

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

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

Unfortunately, as Stock(1987) points out, 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 5) 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 a 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. In support, previous empirical studies have 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.

To avoid using this estimate 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. Alternatively, I could 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.[14] 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 4.2.1 raised the issue of the possible endogeneity of cost in the price equation. 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. Therefore, an oil price series such as the West Texas Intermediate crude price provides an ideal instrument.

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.[15] To test for the exogeneity of cost in Equation 5, I estimate the model using instrumental variables and OLS.

[14]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, $\approx .29$.

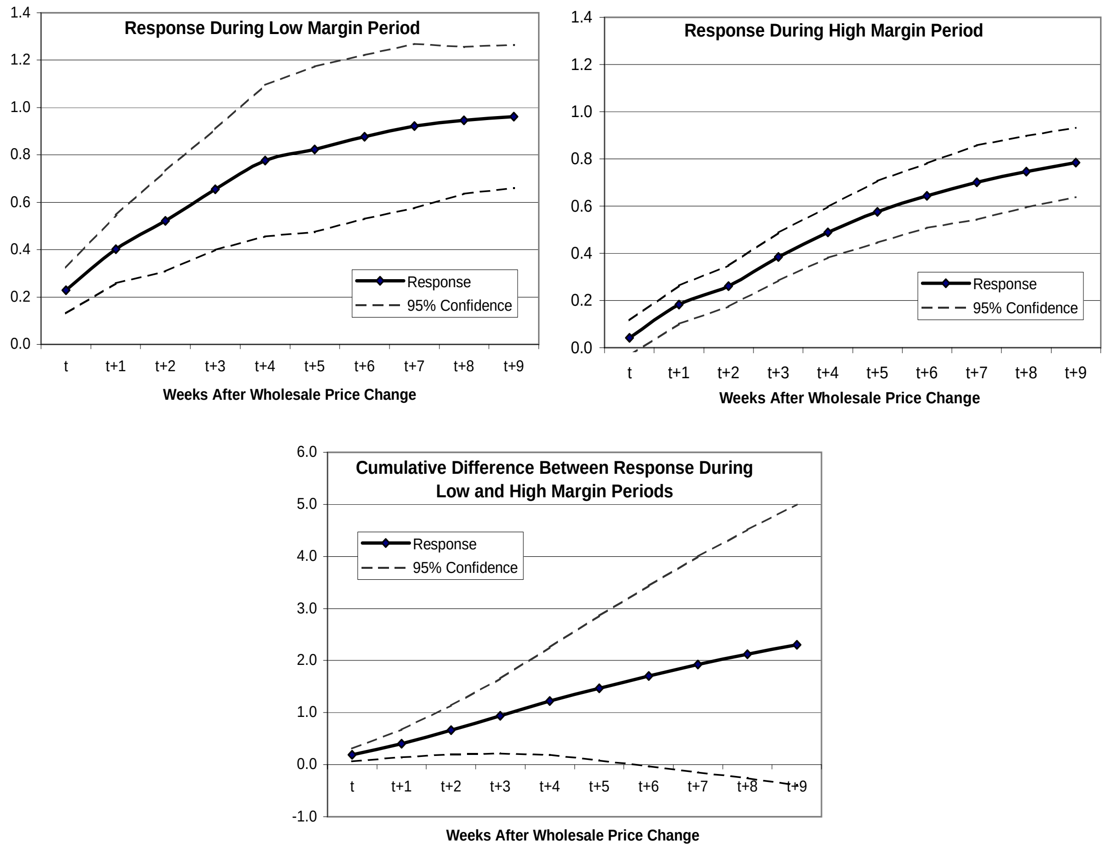
[15]Specification testing to determine the proper lag lengths has been somewhat problematic. Additional lags continue to be significant when included (even for well above 10 lags), however additional lags sacrifice degrees of freedom and appear to have very little effect on the estimates of price response.

Robust standard errors are clustered by time period to remove the correlation of errors across stations within a week. Current and 2 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 B, Table B1. 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 were 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 remains above it's long run equilibrium level. Therefore, the CRF calculated for a cost change during a high margin period may differ from that of a low margin period. Figure 3 presents the estimated CRFs during high and low margin periods. Standard errors and confidence intervals for these response functions are estimated using the delta method. The results indicate 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. The cumulative difference between these two response functions is also reported and is significant until the sixth week following the shock. The cumulative difference in period n is the sum of the differences of the two CRFs over the previous $n - 1$ periods. This represents the total difference in price paid (cents/gallon) from 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 they would save from a 10 cent decrease during a high margin period. The CRFs calculated from the IV estimation of Equation 5 are reported in Appendix B, Figure B1.

These results are consistent with the prediction of the reference price search model that prices are more responsive to cost when margins are low. Predictions of the focal price collusion model are also consistent with the findings, since collusive prices are high and unresponsive to cost changes. Benabou & Gertner's search model does not predict any

Figure 3: Impulse Response Functions from Estimation of Equation 5



relationship between margins and the response of price to cost.

CRFs can be interpreted as the response of price to a cost shock that pushes the system temporarily out of its long run equilibrium. In that case, the CRF constructed from high margin coefficients describes the response to a negative cost change that leaves p above its long run equilibrium relationship. Similarly, the response to a positive cost change is estimated by a CRF constructed from low margin coefficients. Therefore, comparing the difference in these two CRFs can give some indication of asymmetry in the adjustment of price to positive and negative changes. However, the model in Equation 5 does explicitly allow different price response behavior based on the direction of the cost change.

4.2.3 Refinements to the Nonlinear Structure

Previous empirical studies of asymmetric adjustment have directly estimated separate price response functions for cost increases and decreases. The results generally indicate that price responds more rapidly to cost increases than cost decreases. 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. It may be more accurate to estimate the CRF to a negative cost change by only using observations of negative cost changes during high margin periods.

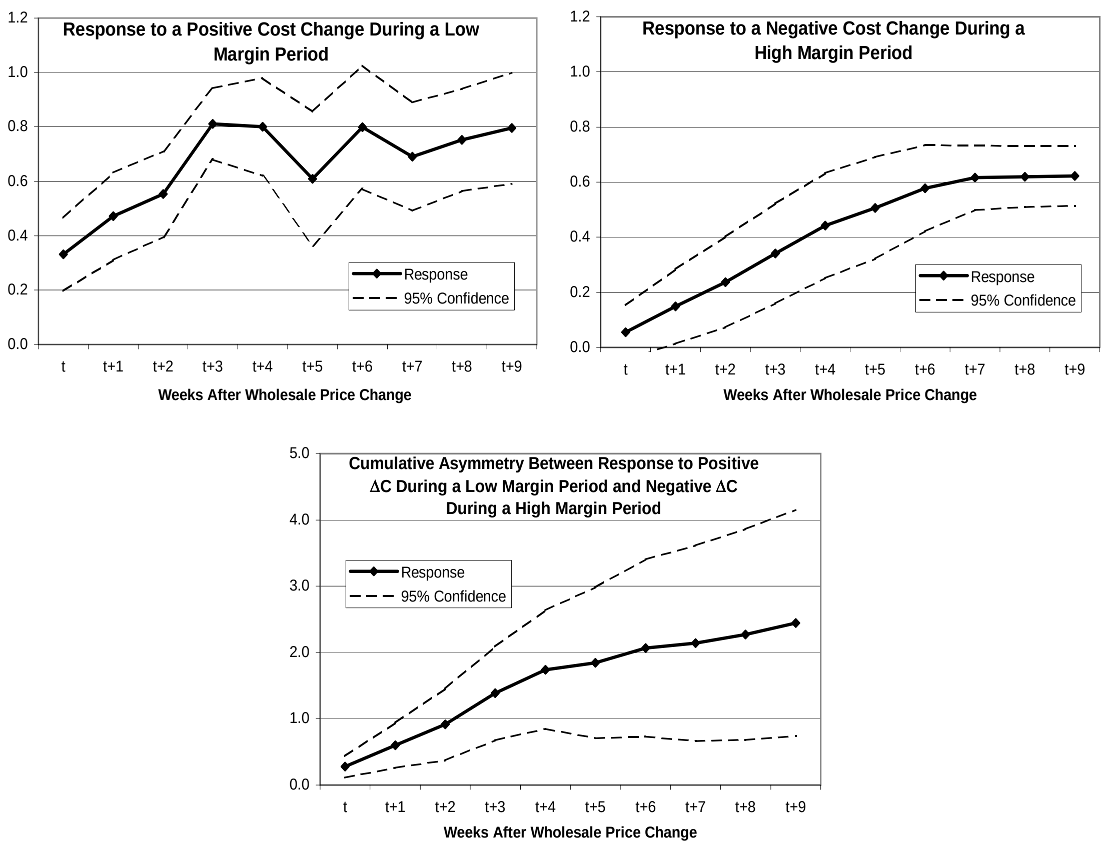
To relax this assumption separate coefficients can be estimated for positive and negative observations of each lagged cost and price change:

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

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

In this model CRFs can be more accurately constructed to predict how prices in equilibrium would respond to a positive or negative cost change. Now an CRF for a negative cost change involves the coefficients of negative cost changes during a high margin period. Similarly the CRF for a positive change involves the coefficients of positive cost changes during a low margin period. These functions represent the response of price to a change in cost given that price and cost start in long run equilibrium. Equation 6 is estimated by OLS in the same manner as Equation 5. The results of these CRFs are reported in Figure 4. Once again, a Hausman exogeneity test can not be rejected. Nevertheless, results of the corresponding IV estimation can be seen in Appendix B, Table B2 and Figure B2.

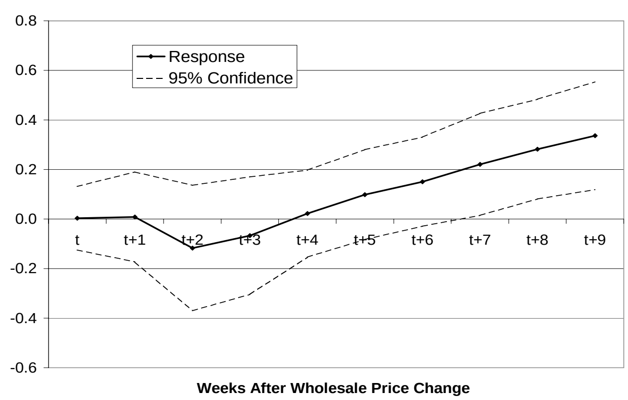
Figure 4: Impulse Response Functions from Estimation of Equation 6



The asymmetry of these response estimates are slightly larger and more precisely estimated than in Figure 3. The cumulative asymmetry estimates are significant for every period following the shock. A Wald test of the equivalence of the models in equations 5 and 6 can be rejected at the .1% level, suggesting that estimating asymmetric response 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.

High margin/positive and low margin/negative cost change coefficients do not appear in CRFs that are assumed to start in equilibrium. However, these coefficients can predict how price responds to cost while out of equilibrium. This is one of the dynamic properties of the theory which I am looking to test. Both the reference price search model and the focal price collusion model predict that prices respond little to cost increases during high margin periods. I would like to identify how much an increase in cost affects the current and future prices which are already out of equilibrium with a margin that is too high. A response function calculated from the high margin/positive cost coefficients can be interpreted in precisely this way. Due to the additive separability of the CRF, this new response function estimates the change in the current response path due to the new increase in cost. Figure 5 contains the estimate of the price response due to a cost increase during a high margin period. It is calculated using the coefficients estimated from Equation 6.

Figure 5: Response to a Positive ΔC During High Margin Period



Estimates suggest that there is no significant effect of an increase in cost during a high margin period for at least 7 weeks. The slow response accumulating in later weeks is likely due to a slow convergence to the new long run equilibrium rather than a direct response to the lagged cost change. Clearly this response is very different than the rapid response estimated for positive cost changes during low margin periods. This difference is strong evidence for the predictions of the reference price search model and the focal price collusion model. It is also a result that previous empirical studies of asymmetric adjustment could not identify while assuming symmetric response to all positive cost changes.

4.3 Station Price Reductions

The reference price search model and the focal price collusion model differ most in their conclusions about individual firm behavior. Firms in the reference price search model are all charging their unilaterally profit maximizing price given demand conditions. Since firms are symmetric they all lower prices to the "no search" price when costs are well below last periods price.

Conversely, in the focal price collusion model prices respond asymmetrically because firms collude when cost falls below past price levels. Firms maintain collusion by charging the previous period's price until a shock causes collusion to break. Average prices would decrease gradually as long as a certain number of firms broke from the collusive price each period. Therefore, as average price is declining, a large number of firms charge either very high prices or very low prices.

These theoretical differences suggest an empirical test determining whether stations decrease prices gradually and with roughly the same pattern, or whether they decrease prices in one particular period and at different times from other stations. If sudden price drops are absent and price patterns of the firms are similar, then focal price collusion can not easily explain the observed adjustment asymmetries.

I test station behavior by constructing time series of the maximum and minimum prices observed in the sample each period. Focal price collusion would predict that the highest prices in the city would be the firms which are colluding at past prices. The lowest prices in the city would be firms in locations where collusion has broken and prices are much more competitive. Therefore, minimum price in the market should not adjust as asymmetrically since it represents a more competitive price. Similarly, the maximum price might adjust much more asymmetrically since it represents the firms which collude the longest. On the other hand, the reference price search model would predict maximum and minimum prices behaving roughly the same as the city average price since firms are

Table 4: 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
Overall Average Price	117.8	132.5	109.0	99.5

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

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. Table 4 shows the correlation matrix of the "min" and "max" prices as well as the city mean price and wholesale cost.

Correlation coefficients of the minimum, maximum and mean prices for each week are much more highly correlated with each other than with the wholesale cost. This shows that even the highest and lowest observed prices are moving about as asymmetrically as the average prices. These results directly contradict the predictions of the focal price collusion model. The lowest prices are still far from competitive, and the highest prices don't maintain collusive asymmetry any longer than the average prices in the city.

High correlations suggest that all stations in the market respond to cost changes similarly, as the reference price search model predicts. This can be more carefully examined by estimating and comparing the response behavior of the mean price and minimum price in the market. CRFs are calculated by estimating the model in equation 6. 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 were estimated in Section 4.2.2. Instead I estimate the model with 3 lagged changes in cost and 2 lagged changes in price. The results are presented in Table 5. 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 very similar estimates of the CRF as the full specification.

Table 5: Minimum and Mean Price Response Function Estimation

CRF for a Positive Cost Change During a Low Margin Period				CRF for a Negative Cost Change During a High Margin Period			
Full Sample Panel Data ($obs = 29320$)				**Full Sample Panel Data** ($obs = 29320$)			
Period	Response	95% UB	95% LB	Period	Response	95% UB	95% LB
t	0.292	0.465	0.119	t	0.059	-0.049	0.168
$t+1$	0.401	0.592	0.210	$t+1$	0.142	0.015	0.268
$t+2$	0.472	0.650	0.294	$t+2$	0.225	0.099	0.351
$t+3$	0.660	0.809	0.511	$t+3$	0.342	0.252	0.433
Mean Price Time Series ($obs = 92$)				**Mean Price Time Series** ($obs = 92$)			
t	0.352	0.565	0.140	t	0.082	0.002	0.163
$t+1$	0.517	0.775	0.258	$t+1$	0.161	0.025	0.296
$t+2$	0.558	0.821	0.294	$t+2$	0.237	0.067	0.407
$t+3$	0.686	0.906	0.467	$t+3$	0.345	0.153	0.537
Minimum Price Time Series ($obs = 92$)				**Minimum Price Time Series** ($obs = 92$)			
t	0.294	0.478	0.110	t	0.115	0.021	0.209
$t+1$	0.460	0.674	0.245	$t+1$	0.204	0.055	0.354
$t+2$	0.541	0.767	0.315	$t+2$	0.274	0.086	0.462
$t+3$	0.665	0.870	0.461	$t+3$	0.397	0.202	0.592

Cumulative Asymmetry Between CRF of Positive ΔC During Low Margin Period & Negative ΔC During a High Margin Period			
Full Sample Panel Data ($obs = 29320$)			
Period	Response	95% UB	95% LB
t	0.233	0.436	0.030
$t+1$	0.492	0.893	0.091
$t+2$	0.739	1.337	0.140
$t+3$	1.056	1.777	0.336
Mean Price Time Series ($obs = 92$)			
t	0.270	0.497	0.043
$t+1$	0.626	1.126	0.126
$t+2$	0.947	1.745	0.148
$t+3$	1.288	2.343	0.232
Minimum Price Time Series ($obs = 92$)			
t	0.179	0.385	-0.028
$t+1$	0.434	0.886	-0.018
$t+2$	0.701	1.422	-0.019
$t+3$	0.970	1.939	0.001

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.[16] The estimated CRFs for the mean price and the minimum price are presented next. As in Table 4 the 2nd percentile price is used instead of the minimum to avoid outliers.

The response functions confirm the results of the correlations in Table 3. It appears that the lowest prices in the market adjust to cost changes at roughly the same speed as the average station. The point estimates are only slightly less asymmetric for the minimum price than the mean price. The cumulative asymmetry for the minimum price series is just on the borderline of significance at the 95 percentile. There is little evidence that the lowest prices are responding as they would in a competitive market, as the focal price collusion model would imply. Given these findings, its unlikely that patterns of collusion and punishment are the main cause of asymmetric adjustment in this market. Stations appear to change prices in unison as the reference price search model predicts.

5 Conclusions

The empirical evidence in Section 4 suggests that the reference price search model predicts the type of price adjustments observed in retail gasoline. The two alternative models discussed in this paper are not consistent with some of these observed patterns. Table 4 summarizes how the theoretical models match up with the empirical findings. The three testable implications identified in Section 4 are listed along with the corresponding theoretical prediction from each model. Theoretical predictions consistent with the empirical results are labeled in bold font. Of the theories presented only the reference price search model predicts all of the empirical results.

This empirical evidence does not definitively 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 all other existing models of competition and

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

Table 6: How the Hypothesized Models Compare with the Empirical Evidence

(**Bold** font indicates correct theoretical prediction.)

Empirical Tests	Benabou & Gertner Search Model	Focal Price Collusion Model	Reference Price Search Model
When are profit margins high?	When prices are rising and falling	**When prices are falling**	**When prices are falling**
When do prices respond to cost changes?	At all times	**Only when margins are low**	**Only when margins are low**
How and when do stations reduce prices?	**Gradually and in unison**	Suddenly and at different times	**Gradually and in unison**

consumer behavior. The empirical results clarify the necessary predictions of any model proposed to explain retail gasoline price asymmetries.

Any proposed 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 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. [17] 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

[17] 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.

are rising.[18] It is hard to imagine why such a collusive strategy would arise within this (or any) market.

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

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Appendix A: 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.[19] This type of concept is not consistent with 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.

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

Appendix B: Additional Results

Table B1: First Stage IV Estimates for Equation 6

Dependant Variable	Δc_t^{hm}	Δc_t^{lm}
Δoil_t^{hm}	2.448**	1.08
	(.525)	
Δoil_t^{lm}		2.534**
		(1.074)
$\Delta \text{oil}_{t-1}^{hm}$	-.488	
	(.839)	
$\Delta \text{oil}_{t-1}^{lm}$		.780
		(.971)
$\Delta \text{oil}_{t-2}^{hm}$	.426	
	(.677)	
$\Delta \text{oil}_{t-2}^{lm}$		2.727**
		(1.282)
P(F-stat)^A	.0001	.0559
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

Figure B1: Impulse Response Functions from IV Estimation of Equation 6

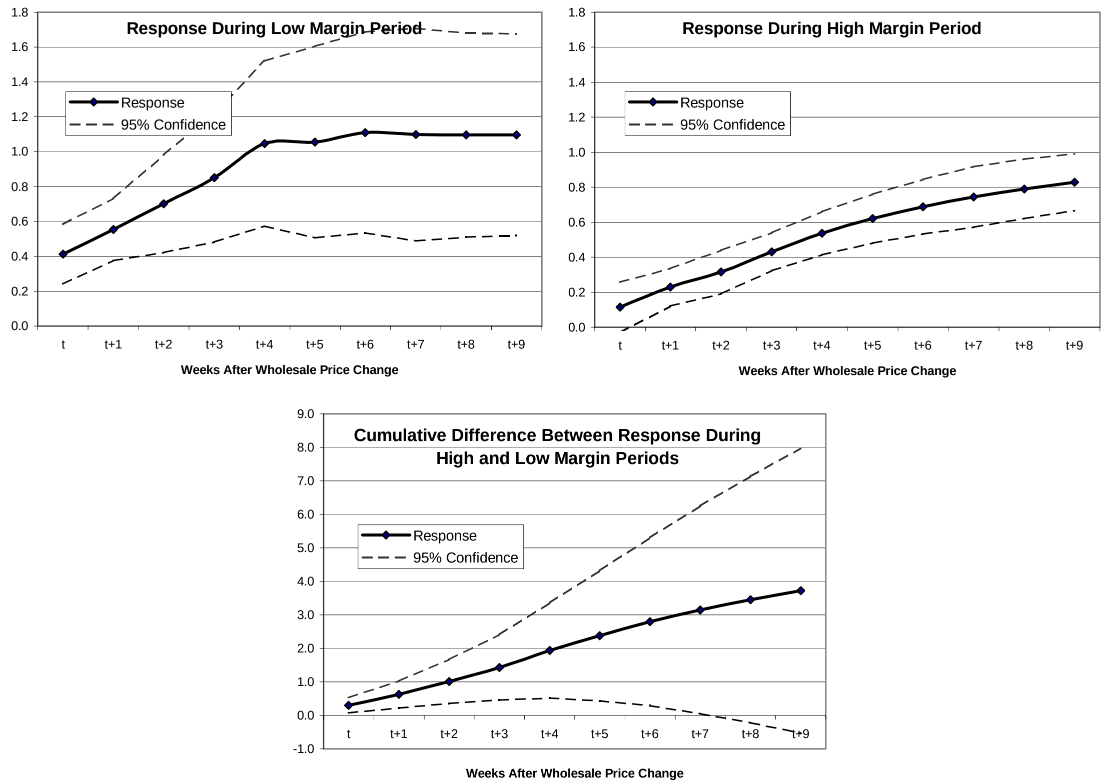


Table B2: First Stage IV Estimates for Equation 7

Dependant Variable	$\Delta c_t^{+,hm}$	$\Delta c_t^{-,hm}$	$\Delta c_t^{+,lm}$	$\Delta c_t^{-,lm}$
$\Delta \text{oil}_t^{+,hm}$	.581	1.08		
	(1.06)	(.868)		
$\Delta \text{oil}_t^{+,lm}$			6.334**	.517
			(1.898)	(.954)
$\Delta \text{oil}_t^{-,hm}$	.491	2.06**		
	(.424)	(.465)		
$\Delta \text{oil}_t^{-,lm}$			-1.383*	1.556**
			(.799)	(.790)
$\Delta \text{oil}_{t-1}^{+,hm}$	-.153	-1.111		
	(.839)	(1.13)		
$\Delta \text{oil}_{t-1}^{+,lm}$			1.908	-.970
			(1.902)	(1.192)
$\Delta \text{oil}_{t-1}^{-,hm}$				
$\Delta \text{oil}_{t-1}^{-,lm}$				
$\Delta \text{oil}_{t-2}^{+,hm}$	-.430	2.072**		
	(.772)	(.956)		
$\Delta \text{oil}_{t-2}^{+,lm}$			-.218	1.121
			(1.122)	(1.192)
$\Delta \text{oil}_{t-2}^{-,hm}$	-.273	-.748*		
	(.412)	(.405)		
$\Delta \text{oil}_{t-2}^{-,lm}$			-2.444	1.410
			(2.017)	(1.812)
P(F-stat)^A	.705	.000	.010	.222
obs	27975	27975	27975	27975

Δoil_t represents the change in West Texas Crude Oil Price

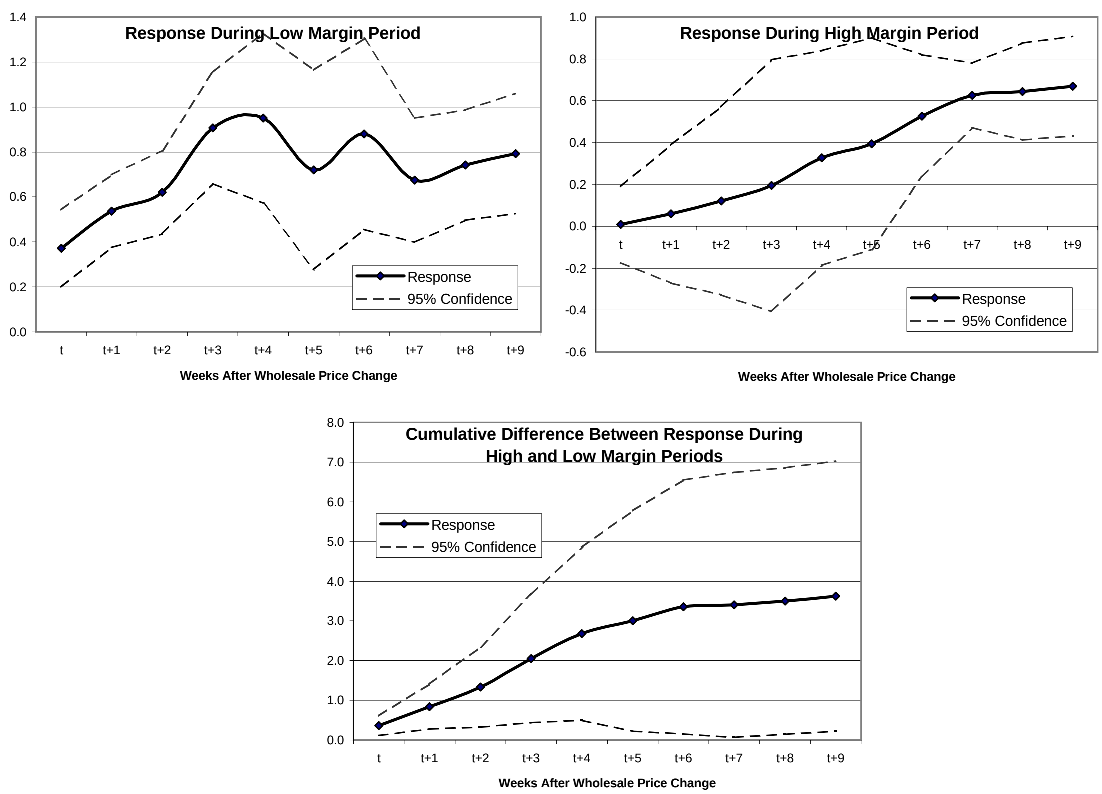
Robust-Clustered standard errors are presented

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 B2: Impulse Response Functions from IV Estimation of Equation 7



Appendix C: Simulations of the Equilibrium Price Relationship

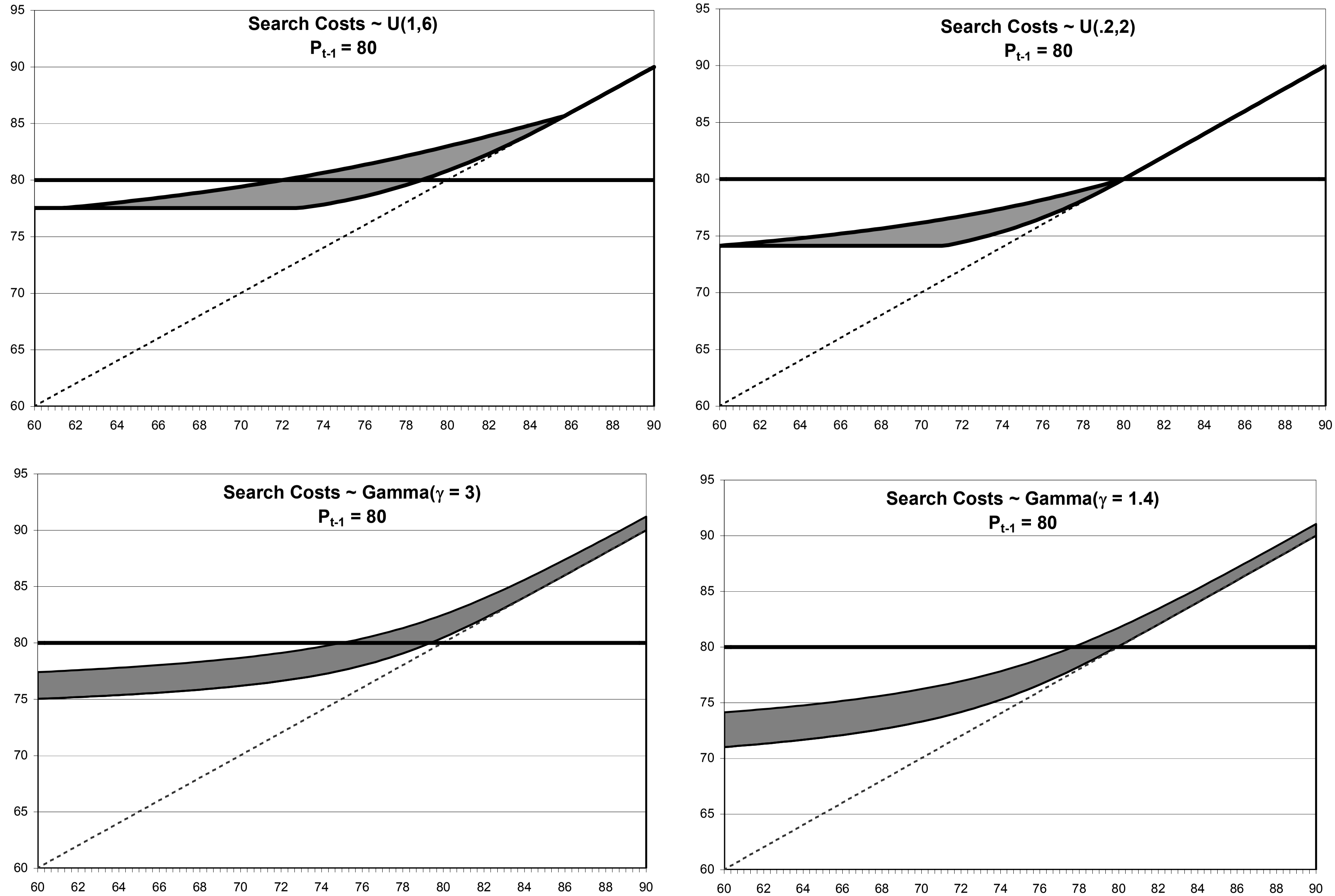
Section 2 does not solve for the explicit equilibrium relationship between price and marginal cost. Therefore, I have simulated the relationship under several different assumptions about the distribution of consumer search costs. The presentation in the paper describes a distribution of search costs 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 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$= \gamma$. 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 periods 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

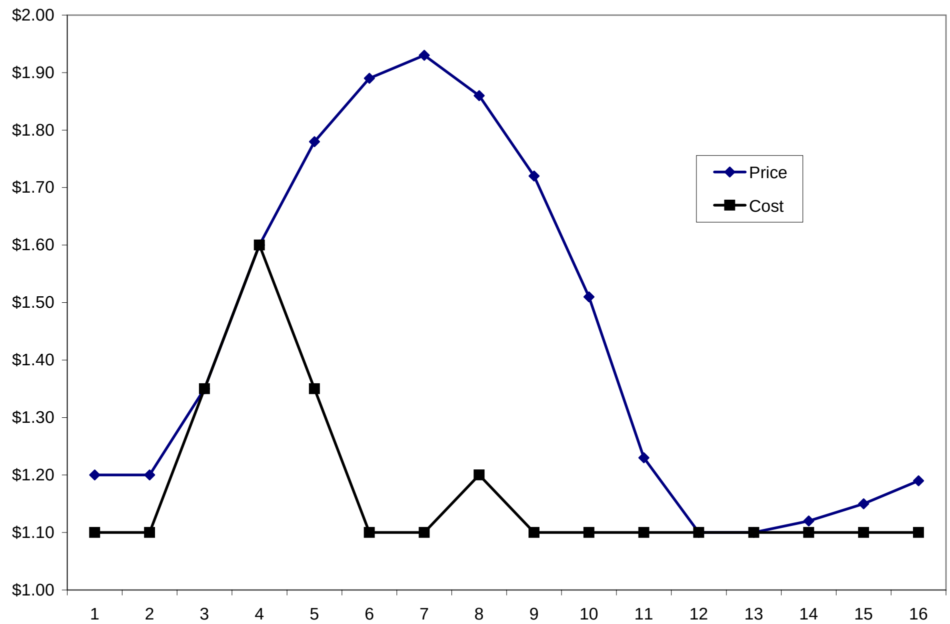


Figure D: Asymmetric price response to changes in MC.

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 periods 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 section 4.2.2 I discuss the possibilities of bias in the estimation of the cointegrating vector of p and c. 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.[20] 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:

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

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, in small samples this estimate ignores the short run dynamics between p and c which are created by the error correction relationship.

[20]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.

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 procedure is the OLS estimate of ϕ in the following equation:[21]

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

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.

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