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ABSTRACT

Our empirical investigation confirms the common belief that retail gasoline prices react more quickly to increases in crude oil prices than to decreases. Nearly all of the response to a crude oil price increase shows up in the pump price within 4 weeks, while decreases are passed along gradually over 8 weeks. The asymmetry could indicate market power of some producers or distributors, or it could result from inventory adjustment costs. By analyzing price transmission at different points in the distribution chain we investigate these theories. We find that some asymmetry occurs at the level of the competitive spot market for gasoline, perhaps reflecting inventory costs. Wholesale gasoline prices, however, exhibit no asymmetry in responding to crude oil price changes, indicating that refiners who set wholesale prices are not the source of the asymmetry. The most significant asymmetry appears in the response of retail prices to wholesale price changes. We argue that this probably reflects short run market power among retail gasoline sellers.

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I. Introduction

The 1990-91 Persian Gulf crisis brought to attention again the response of retail gasoline prices to fluctuations in world oil prices. Consumer groups and even a Republican president expressed concern about gasoline price "gouging" and "profiteering." Some critics complained that retail prices reflected the recently increased price of oil, rather than the historical price at which the companies had purchased the oil used to make the gasoline. Of course, prices in competitive markets should reflect the opportunity cost of the inputs, not the accounting cost, so this complaint was easy to dismiss. Other observers, however, asserted that gasoline prices react more quickly to increases in crude oil prices than to decreases. If true, this would appear to reflect a significant departure from the standard competitive model.

In this paper, we test for asymmetry in the speed of retail price responses and find supporting evidence. Such asymmetries, however, are as inconsistent with textbook monopoly behavior as they are with simple models of competition. Although such a pricing pattern could indicate market power at some level of the distribution chain, the connection is not immediately apparent. Many critics of gasoline price movements have placed the "blame" for asymmetric retail price responses on the major refining companies, but the cause could also lie at other points along the distribution chain.

The process of making and distributing gasoline for consumer use can include from one to as many as four market transactions. A fully integrated oil company could obtain oil from its own wells, refine it in its own refineries, distribute the gasoline through its own delivery trucks, and finally sell it to consumers from a station that the company owns and operates. More frequently, however, some or all of the crude oil a refiner uses is purchased from another company. Often, a refining company will sell some output as generic gasoline to another marketer or will buy some of the gasoline it needs to supply its retailers, rather than produce it all in its own refinery. Further downstream, most major oil companies deliver a substantial proportion of their branded gasoline to retailers through some intermediary and none of the major oil companies owns more than one-third of their name-brand stations.

Thus, transmittal of a price change from crude oil to retail gasoline may depend on the response in many intermediate margins. Most service stations and "jobbers" who handle intermediate transactions set prices without direct intervention from the gasoline refiners, so these decisions are not completely coordinated between upstream and downstream companies.[1] Whether the production and distribution process occurs wholly within one firm or involves intermediate transactions, a company faces opportunity costs at every point in the process. Because market transactions occur and price data are available at most points in the production and distribution process, we observe measures of these direct or opportunity costs.

In the following section, we describe the production and distribution process in greater detail and, in this context, discuss the sources and appropriateness of the data that we analyze. In section III, we test for and find that retail gasoline prices respond asymmetrically to changes in crude oil prices, increasing in response to crude price rises faster than they decrease in response to crude price declines. Nearly all of the response to a crude oil price increase shows up in the pump price within 4 weeks, while decreases are passed along gradually over the 8 weeks following the crude oil price change.

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[1] Although the refiner cannot set prices at retailers that it does not own and operate, nonlinear pricing and and other incentives from refiners are common in an effort to lessen the double marginalization problem. See Shepard (1991b) for a detailed description of the contractual relationships between refiners and dealers and Temple, Barker, and Sloan, Inc. (1988) for a description of common distribution practices.

In section IV, we present theories that could link such asymmetries to each of the distribution tiers. We suggest that the asymmetry could result from inventory costs and constraints – particularly the asymmetry that may exist because inventories must be non-negative – or that it could result from imperfections in competition at some stage of the distribution process. Sellers at the refinery, wholesale, or retail points in the distribution chain might exhibit short run oligopoly behavior in response to decreases, attempting to maintain the former price until some other seller deviates and cuts price. An alternative explanation relying on a market imperfection, which would apply only to the retail market, is that imperfect information on the part of buyers causes sellers to be less competitive when input prices are variable because a buyer is more likely at such times to attribute individual price changes to market-wide cost effects.

By analyzing the price response at each level of distribution, in section V we attempt to distinguish between the competing explanations for the asymmetric response. We find significant asymmetries in the transmission of crude oil price changes to the changes in the spot price for generic gasoline. Although increases and decreases are both passed through within 2 weeks, increases are passed through significantly faster than decreases over the first two weeks. At the next level of transmission, however, we find evidence of a small, and weakly significant, "reverse" asymmetry: wholesale gasoline prices respond somewhat more quickly to decreases in spot prices for generic gasoline than to increases in spot gasoline prices. Finally, in the transmission of price changes from wholesale to retail we find the statistically strongest evidence of an asymmetry, with retail prices changing much more quickly in response to wholesale price increases than to wholesale decreases. The spot market evidence appears to lend some support to inventory theories, though the asymmetry at this level seems larger than could easily be explained by inventory costs alone. The asymmetry in the wholesale-retail transmission indicates that imperfect competition in retail markets may be substantially responsible for the asymmetric response of retail gasoline to crude oil price changes.

II. The Production and Distribution of Gasoline

The production and distribution of gasoline in the U.S. is illustrated in figure 1. Motor gasoline is one of many products that can be made from refining crude oil, along with diesel fuel, kerosene, jet fuel, heating oil, plastics and other products. The mix of outputs can be altered by changing refining processes, but the scope for such output substitution is limited, while maintaining efficient production. During our sample period gasoline averaged about 45% (by volume) of refined output at U.S. refineries.[2]

Gasoline produced at U.S. refineries, and the 5% of U.S. gasoline consumption that is imported, is distributed through many channels. Refiners often sell large quantities of generic gasoline directly from the refinery to distributors or other refiners in spot transactions. Gasoline may be shipped to the distribution terminal in a city and sold there as "branded" gasoline (with company-specific additives and with the right to use the refiner's name at resale) at a branded "terminal" (also known as branded "rack") price. Gasoline from a name-brand refinery may also sold as generic gasoline at the terminal, without permission to use the refiner's name. Finally, "unbranded" refineries – those that do not operate their own chain of retail outlets – sell unbranded gasoline at their city terminals for resale at "unbranded" stations – stations that do not carry the name of a major refiner.

Once gasoline arrives at the city terminal it can be distributed directly by the refiner ("direct-supplied") or through middlemen know as "jobbers."

[2] Energy Information Administration (1991), p. 16.

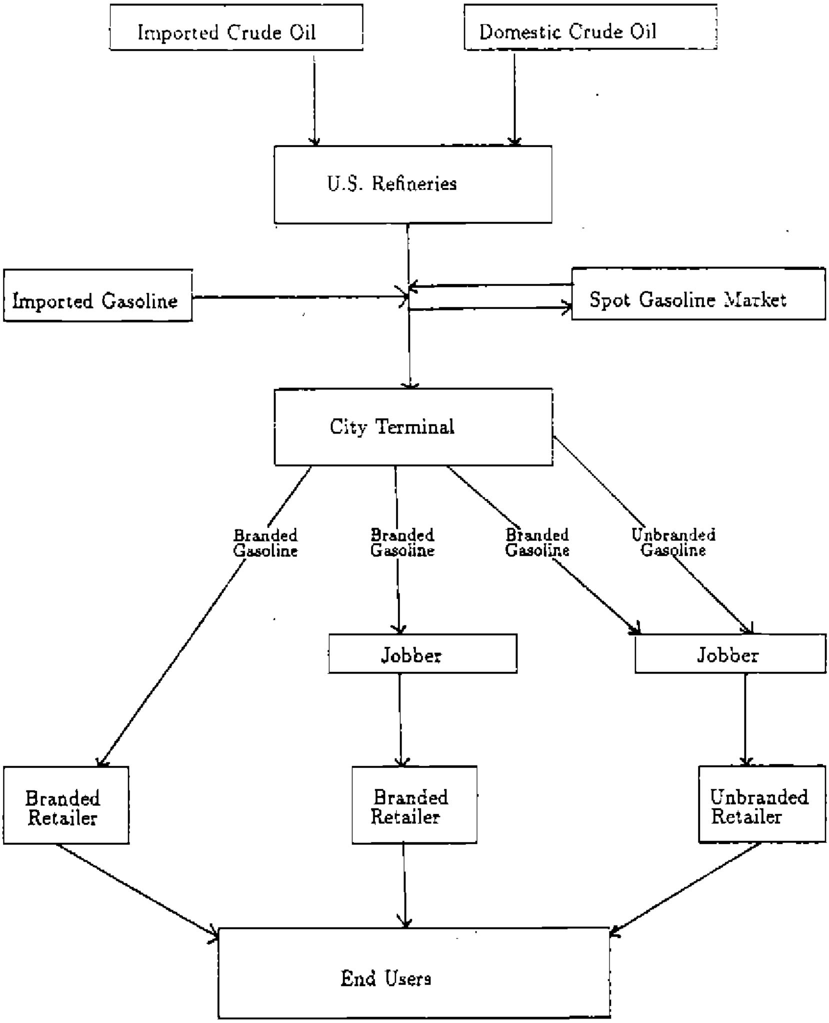

Figure 1

About 55% of U.S. gasoline is distributed by "jobbers" or through other companies that are not controlled by refiners.[3] A typical jobber supplies stations of many different brands and generally owns many of the stations it supplies. A jobber might, for instance, supply 5 Shell stations, 3 Chevron stations, and 5 unbranded stations, some of which the jobber owns and operates. All gasoline sold at the Shell stations must be purchased at the local

[3] Temple, Barker, and Sloan, Inc. (1988), p. 19.

Shell terminal by the jobber, and similarly for the Chevron stations. The unbranded stations can be supplied with either the product of Chevron or Shell, or gasoline from an unbranded refinery. The terminal price for branded gasoline is the same regardless of the final use – branded or unbranded – to which it will be put. Thus, the branded refiner competes for its marginal sales at the terminal with unbranded refiners, which only sell gasoline at the terminal for resale at unbranded stations. The terminal price of branded gasoline is usually above the terminal price of unbranded gasoline, but the difference seldom exceeds 3/4 of a cent.[4]

Some gasoline is not purchased by jobbers at the terminal for delivery, but is transported from the terminal to the retailer by the refiner. Most of these direct-supplied stations are operated by an independent franchisee, but some are owned and operated by the refiner. For company-operated stations, no financial transaction occurs at the point of delivery, while franchisees purchase the delivered gasoline at a "dealer tankwagon" price. About 17% of U.S. gasoline is sold through refiner-operated stations.[5]

At each point in the distribution process many arms-length transactions occur between companies. The prices of these exchanges indicate both the direct costs to the buyers and the shadow costs that vertically integrated firms face. Major refining companies, for instance, must frequently decide between refining additional crude oil or buying generic gasoline on the spot market, presumably equating the costs of these two sources on the margin. Thus, we use market transaction prices as indicators of the economic cost of the product at each stage of distribution.

The cost of crude oil can be represented by the daily spot market price

[4] Branded terminal prices exceed unbranded terminal prices by an average of about 1/4¢ in our dataset.

[5] Temple, Barker, & Sloan (1988), p. 19.

of West Texas Intermediate (WTI) crude oil. More than 80% of oil traded worldwide is now traded at a spot price or under a contract with a price tied to the spot price.[6] WTI is the benchmark crude oil watched most closely in the U.S.[7] One criticism of using the spot price is that there isn't an actual marketplace for spot crude oil transactions or real-time reporting of prices. Rather there are many independent trades that take place at different locations among well-informed traders. The price reported as the spot price is taken from a survey of traders each day, as reported by *Dow Jones International Petroleum Report* and published in the *Wall Street Journal*.[8] We have also constructed a price change series using one-month futures prices for sweet crude oil, contracts that are traded on the New York Mercantile Exchange (NYME). This series has a correlation of 0.95 with the change in WTI spot prices. The results of our analysis are not altered by the use of futures prices instead of spot prices.

Generic gasoline prices are reflected in the spot gasoline prices for delivery to New York and the Gulf Coast.[9] As with crude oil, gasoline spot prices are determined by a daily survey of major traders, as reported by *Oil Buyers' Guide* and published in the *Wall Street Journal*. A gasoline price change series from one-month ahead futures contracts traded on the NYME has a correlation of 0.88 with the change in Gulf Coast delivery spot

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[6] See Razavi (1989).

[7] The two other types of crude oil actively traded on U.S. spot markets are North Slope Alaska and West Texas Sour crude. The daily prices of each has a correlation of 0.99 with WTI over our sample period. The correlation of daily price changes over our sample period is 0.90 between WTI and North Slope crude and 0.72 between WTI and West Texas Sour crude. The basic results we present are not sensitive to the choice of crude price used.

[8] Razavi (1989) discusses potential reporting errors. Support for the reliability of these spot prices, however, is evident from the fact that many long-term contracts are indexed by this price.

[9] The two prices have a correlation of 0.99 over our sample period. The daily price changes have a correlation of 0.72.

prices. We use the Gulf Coast spot price for our analysis, but the results are unchanged by switching to the New York spot prices of the NYME futures price series.

The branded and unbranded city terminal prices are averages of 17 cities east of the Rocky Mountains from weekly surveys conducted by Lundberg Survey on Friday of each week. Spot markets are not as well established in the west and the spot and futures commodity prices that we have are for delivery in the east, so we omit cities in the western U.S. from our analysis.

As mentioned above, there is often one more transaction point for gasoline, when the product is delivered and sold to the retailer at a dealer tankwagon price. Unfortunately, the data available on these transactions are incomplete – they cover only direct-supplied stations – and probably unreliable – refiners admit that they frequently discount off of the posted DTW price.[10]

Retail gasoline prices present a number of data problems. The retail price we use is the average of unleaded regular self-service gasoline prices in 42 U.S. cities east of the Rocky Mountains collected semi-monthly by Lundberg Survey on either the first and third or second and fourth Friday of each month.[11] The first complication with the retail price data is that all but one of the cities are surveyed only once each month, either always in the first survey or always the second survey of the month. The first survey average price for each month is the average of 22 cities and the second is

[10] The analysis that we have done with these data yield results consistent with our other findings, but we do not include these results due to the questionable quality of these data.

[11] Unfortunately, these seem to be the best available retail gasoline survey data. Other sources, such as the *Oil and Gas Journal Database*, use wholesale prices to estimate approximate retail prices. As with all prices in this study, the Lundberg prices are exclusive of excise or sales taxes, and are in current dollars.

the average of 21 cities, with one city (Atlanta) appearing in both surveys. To correct for different means for the different cities included in the two surveys, we include a fixed effect parameter for the second survey of the month in all of the data analysis.[12] The second complication is caused by the irregular sampling period. About 85% of the surveys occur two weeks after the prior survey, but 15% occur three weeks later. The weekly periodicity of the other price data, however, allow us to correct for this, and to potentially even recover all of the weekly adjustment parameters.

Figure 2 presents the semi-monthly price movements of retail, terminal and spot market unleaded gasoline and spot WTI crude oil over our sample period from January 1986 to December 1990. This figure indicates that retail gasoline prices are less volatile than upstream gasoline prices or spot crude oil prices. The standard deviations of semi-monthly changes in average retail, average terminal, spot market gasoline and spot market crude oil prices are, respectively, 2.91¢, 4.12¢, 5.74¢, and 4.23¢. The smoother retail prices are indicative of the lags that we find in the adjustment of retail prices to changes in upstream prices and to the less-than-full adjustment that retail prices exhibit, *e.g.*, a 1¢ increase in the spot price of gasoline or crude oil leads to a long-run increase in retail gasoline prices of less than 1¢.

Figure 2 also shows that margins between gasoline and crude oil prices (*e.g.*, spot gasoline price minus spot crude oil price) exhibit substantial serial correlation. The explanation for this pattern lies in the determinants of petroleum product supply and demand. Refiners can meet an increased demand for gasoline by squeezing more gasoline from each barrel of crude, by refining more crude, or by raising the wholesale gasoline price.

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[12] The estimated difference in average prices was always around 1.5¢ and highly statistically significant. Tests for changes in this difference over time did not indicate that it changed significantly within our sample.

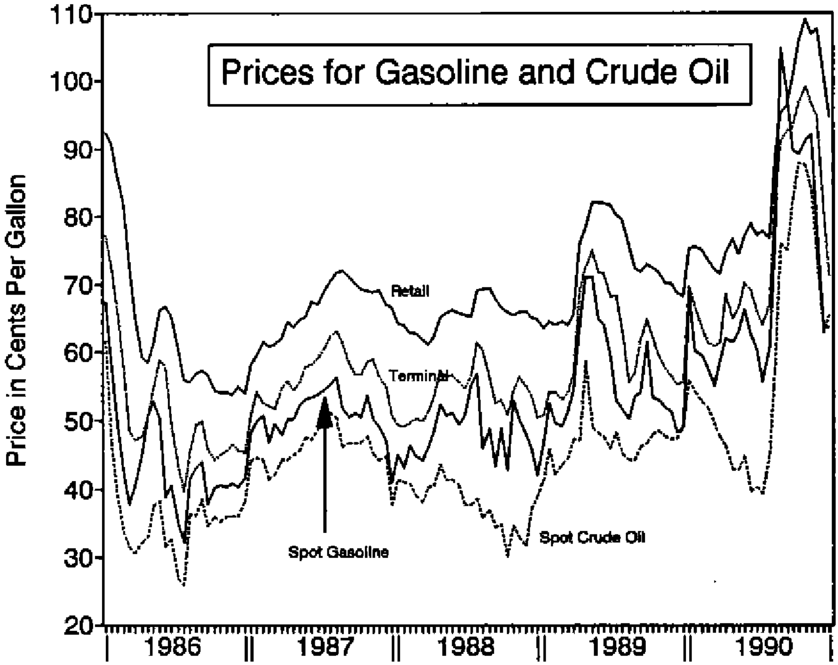

Figure 2

Refiners with sophisticated upgrading capacity (catalytic cracking, hydro cracking, and coking) have some flexibility to vary gasoline production by changing the severity of crude processing, but these refiners tend to be inframarginal sources of supply. The marginal source of supply comes from running increased or decreased quantities of crude in less sophisticated refineries. These refineries are reluctant to run more crude if they expect low prices for heavier products (*e.g.*, heating oil), which in these refineries are unavoidable by-products of gasoline manufacturing. Thus, when refiners anticipate low margins for heavy products, or when refiners underestimate gasoline demand, gasoline margins will rise or tend to stay high. Conversely, gasoline margins will remain low if margins on heavy products are expected to be high enough to entice marginal refiners to run large amounts of crude and continue supplying gasoline in a depressed market.[13]

III. Do Gasoline Prices Respond Asymmetrically to Oil Price Changes

III.1 Adjustment Model

We begin the empirical analysis of gasoline pricing by testing the common belief that retail gasoline prices adjust more quickly to increases in crude oil prices than to decreases in crude oil prices. To estimate the rate at which gasoline prices adjust to crude oil price changes, we assume a simple linear long run relationship between retail gasoline and crude oil prices, $R = \phi_0 + \phi_1 C$. While we recognize that the adjustment of retail prices to changes in crude prices is not instantaneous, we assume that the adjustment function is time-invariant during our sample period and is independent of the absolute magnitude of the crude oil price change. Defining $\Delta C_t = C_t - C_{t-1}$ and $\Delta R_t = R_t - R_{t-1}$, the adjustment could be modeled as:[14]

$$\begin{aligned} \Delta R_t^t &= \beta_0 \ \Delta C_t \\ \Delta R_{t+1}^t &= \beta_1 \ \Delta C_t \\ &\vdots \\ \Delta R_{t+n}^t &= \beta_n \ \Delta C_t \end{aligned} \qquad [1]$$

[13] The complex interdependence of petroleum supply and demand is reflected in the following observation from the *Petroleum Economist* (August 1988, p. 280): "Gasoline is becoming increasingly tight and straining upgrading capacity, chiefly as a result of the increased proportion of low-lead or unleaded requirements, but this simply creates surplus problems for the other products and accounts for caution on throughput levels even with superficially attractive refining margins."

[14] We ignore here systematic drift in retail prices that is not associated with crude oil price changes. We do control for such effects, however, in the econometric estimation.

where the superscript on ΔR indicates that it is solely the change resulting from the period t change in crude oil price and n is the number of periods it takes for retail prices to complete adjustment to the period t change in crude oil prices.

Under these assumptions, the total change in retail gasoline price in any period t will depend on the crude oil price changes in the previous n periods.

$$\begin{aligned} \Delta R_t &= \Delta R_t^t + \Delta R_t^{t-1} + \ldots + \Delta R_t^{t-n} \\ &= \sum_{i=0}^{n} \beta_i \Delta C_{t-i} \end{aligned} \qquad [2]$$

Equation [2], however, imposes symmetric responses to increases and decreases in crude oil prices. Recognizing that the adjustment process could be different for increases than for decreases, we instead assume

$$\begin{aligned} \Delta R_t^t &= \beta_0 \ \Delta C_t \\ \Delta R_{t+1}^t &= \beta_1 \ \Delta C_t \\ \vdots \qquad & \qquad \vdots \\ \Delta R_{t+n}^t &= \beta_n \ \Delta C_t, \end{aligned} \qquad [3a]$$

if $\Delta C_t > 0$, and

$$\begin{aligned} \Delta R_t^t &= \gamma_0 \ \Delta C_t \\ \Delta R_{t+1}^t &= \gamma_1 \ \Delta C_t \\ \vdots \qquad & \qquad \vdots \\ \Delta R_{t+n}^t &= \gamma_n \ \Delta C_t, \end{aligned} \qquad [3b]$$

if $\Delta C_t \leq 0$.[15]

Defining

$$\Delta C_t^+ = \max\{\Delta C_t, 0\} \quad \text{and} \quad \Delta C_t^- = \min\{\Delta C_t, 0\} \qquad [4]$$

[15] The choice of assigning the $\Delta C_t = 0$ cases to the estimates of γ or β will have no effect on the parameter estimates, because no change due to the zero change in crude oil prices will be expected, by assumption.

the adjustment of retail gasoline prices to crude oil price changes, allowing for the possibility of asymmetric adjustment rates, would be:

$$\Delta R_t = \sum_{i=0}^{n} (\beta_i \ \Delta C_{t-i}^{+} + \gamma_i \ \Delta C_{t-i}^{-}) \qquad [5]$$

III.2 Econometric Issues

A number of econometric issues must be address before proceeding with estimation of an equation similar to [5]. The issues that we discuss here arise in the estimation of all of the downstream price transmissions. Additional complications are present when we estimate the response of retail prices to upstream price changes due to the inconsistent and longer periodicity of the retail price survey data we use. We address the complications specific to estimation using the retail price data in appendix A.

Restrictions Imposed on the Lag Response Structure: The additive lag structure we use places few constraints on the adjustment path, allowing it even to be non-monotonic. It also allows a certain intertemporal independence that may be non-standard. For instance, if the price of crude oil increases by 10¢ per gallon in week t and decreases by the same amount in week $t+1$, our model would not necessarily cause the direction of adjustment to reverse when the crude oil price does. The retail price could continue to rise in week $t+1$.[16] This contrasts with a standard partial adjustment model, an approach that has been used by previous authors studying adjustments to oil price changes.

If the long run equilibrium relationship is assumed to be $R = \phi_0 + \phi_1 C$, then we could estimate a partial adjustment model such as

$$R_t - R_{t-1} = \beta(\phi_0 + \phi_1 C_{t-1} - R_{t-1}). \qquad [6]$$

[16] This would occur in [5] if $\beta_1 > \gamma_0$.

Bacon (1991) tests for asymmetry in adjustment rates by including a quadratic term in the adjustment process:

$$R_t - R_{t-1} = \beta_1(\phi_0 + \phi_1 C_{t-1} - R_{t-1}) + \beta_2(\phi_0 + \phi_1 C_{t-1} - R_{t-1})^2, \quad [7]$$

so that the test of $\beta_2 = 0$ is the test of whether adjustment to increases and decreases in crude oil prices occur equally quickly.[17] The partial adjustment model, however, imposes equal proportional adjustments towards the new equilibrium in all periods after a shock to crude oil prices, a serious constraint. Furthermore, Bacon's method for diagnosing asymmetry with a quadratic term imposes a structure on the asymmetry, implying that the asymmetry becomes *proportionally* larger as the difference between the current retail price and the long-run equilibrium price increases. Nonetheless, the qualitative conclusions we draw from the estimation of our model for retail adjustment to crude oil prices, and similar models later in the paper, are supported as well by estimation of the asymmetries from [7], though the results are statistically weaker using the Bacon approach. [18]

Incorporating the Long-Run Relationship Between Gasoline and Crude Oil Prices

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[17] The approach employed by Bacon uses and presented in [7] uses C_{t-1} rather than C_t as the basis for the target R_t. It is standard to use C_t as the basis for the target R_t, but if adjustment time is greater than the periodicity of the data, this can lead to very noisy estimates. Bacon experiments with different lags of C and finds that two weeks, the period between observations in Bacon's data gives the smallest standard errors on the adjustment parameters. He finds evidence of asymmetric adjustment in the hypothesized direction, but characterizes the asymmetry as small. Norman and Shin (1991) use this approach to estimate retail-crude adjustment asymmetry in the U.S. They use estimated weekly retail prices from *Oil & Gas Journal* for 1984-1989. They report finding no indication of asymmetric adjustment, but they use C_t as the basis for the target R_t.

[18] The asymmetric response of retail gasoline to crude oil price changes is significant at only the 9% level using the quadratic partial adjustment model and ignoring the inconsistent periodicity of observations. In applying this method to our data, we use the crude price from the previous retail observation (2 or 3 weeks prior) as the basis for the target R_t. When the contemporaneous crude price is used, the results are statistically and economically insignificant.

The principle advantage of the partial adjustment model over the lag adjustment model presented in [5] is that [5] takes no account of the long run relationship between the prices of the upstream and downstream goods, and the tendency to revert towards that relationship. To address this, we estimate [5] as an error-correction model. The error correction term is the one-period lagged residual from the regression $R_t = \phi_0 + \phi_1 C_t + \phi_2 WK_t$, where WK_t is a time trend. The weekly regression is then:

$$\begin{aligned} R_t - R_{t-1} = & \theta_0 + \sum_{i=0}^{n} (\beta_i \ \Delta C^{+}_{t-i} + \gamma_i \ \Delta C^{-}_{t-i}) \\ & + \theta_1 (R_{t-1} - \hat{\phi}_0 - \hat{\phi}_1 C_{t-1} - \hat{\phi}_2 WK_t) \end{aligned} \qquad [8]$$

The constant term is included to account for the fact that gasoline margins may have systematically changed during our sample period, whether due to inflation or other factors. In estimating the response of either terminal prices or spot gasoline prices to prices of upstream products, we estimate [8] directly with 260 weekly observations from 1986 through 1990. To take account of the longer and inconsistent periodicity of retail price surveys, which make retail price and the error correction variable available only every two or three weeks, we make adjustments to [8], which are explained in Appendix A.

It is possible that the error correction effect may itself be asymmetric. Tests for this, however, failed to reject the null hypothesis at even the 20% level in any of the adjustments that we estimate. To the extent that any asymmetry in adjustment is present, it appears to be captured in the weekly adjustment parameters.

The error correction term also complicates interpretating the parameters to explain the path of adjustment to a one unit change in crude oil prices. The adjustment in the *nth* period after a change in the crude oil price will be the sum of the estimated response parameter from [8] (β_n or γ_n) and the error correction effects over the n weeks. To arrive at an estimate of the full adjustment path, we construct cumulative adjustment functions for both increases and decreases in the price of crude oil, which we explain below and in Appendix B.

Accounting for the Joint Production of Gasoline and Other Petroleum Products: As discussed in section II, refining of gasoline from crude oil also produces other goods that have economic value. The incentives to produce more or less gasoline, and thus the price of gasoline, will depend to some extent on the demand for other refined products. The effect could be positive or negative; while some substitutability among outputs is possible, leading for instance to a positive effect of heating oil demand on gasoline prices, the scope for substitution is limited. If companies refine more crude oil in order to produce more heating oil, the output will include more gasoline, thus depressing the price of gasoline. As mentioned earlier, the latter effect is thought to be more significant in the refining industry.

Despite the role that prices of other petroleum products may play in determining the price of gasoline, it is unlikely that omitting other refined product prices in estimating the adjustment of gasoline to crude oil price changes will lead to significant bias. The exogenous determinants of changes in other refined product prices are principally demand shifts, which are not likely to be correlated over a 1 to 10 week period with changes in the price of crude oil.

Still, we checked the sensitivity of our results to exclusion of other refined product prices by including the current and lagged changes in heating oil prices – the other major refined product and the one for which demand is probably most volatile – in regressions of downstream gasoline prices on crude oil prices. For the same reasons that heating oil prices are likely to influence gasoline price, gasoline prices are likely to influence heating oil prices, so we instrumented for heating oil prices with a measure of heating degree days in the northeastern region. Regressions in both levels and differences indicated that heating oil margins (the price of heating oil minus the price of crude oil) have a significantly negative impact on gasoline prices at each level of the distribution chain. This is consistent with the industry wisdom that gasoline and heating oil are production complements on the relevant margin.

Inclusion of heating oil margins in the adjustment functions had little impact on the estimated asymmetries in the adjustment of gasoline products to crude oil price changes. This is not surprising, since changes in heating oil margins were not significantly correlated with crude prices over our sample period. When heating oil margins were included, the estimated asymmetry was slightly smaller for the response of spot gasoline to spot crude oil and slightly larger for the responses of terminal and retail prices to crude oil price changes, but none of the differences were statistically significant. Of course, the joint production issue does not arise in estimating the response of terminal or retail prices to changes in upstream gasoline prices.

Endogeneity of Crude Oil Prices: Do downstream prices for gasoline influence the price of crude oil? To the extent that U.S. demand for gasoline reflects fluctuations in the worldwide demand for petroleum products (probably due to cyclical fluctuations across the developed countries), U.S. retail gasoline price could be a proxy for causal factors determining the worldwide price for crude oil. Thus, crude oil prices could be endogenous and correlated with the error in our estimated adjustment function. The bias from this possible correlation is unlikely to be very large, for two reasons. First, the retail price of gasoline in the U.S. demonstrates a *negative*, though statistically insignificant, correlation with U.S. GNP growth during the 1980s.[19] Inclusion of a (interpolated) GNP growth variable in the adjustment functions we estimate has virtually no effect on the regression results.

Second, week to week changes in the world demand for petroleum products are likely to be much smaller than week to week changes in world oil supply factors, including changes in beliefs about future supply. Thus, when we observe the relationship between the change in downstream prices of gasoline over a one to three week period and change in upstream gasoline of crude oil prices during the previous 10 weeks, the dominant effect that we are likely to be observing is that of the upstream price on the downstream.

Stationarity and Cointegration of Time Series Variables: Augmented Dickey-Fuller tests on the levels of prices reveal that the individual price series are first difference trend stationary.[20] Upon differencing, the correlograms for spot crude oil and spot gasoline are not quite flat, but show no obvious pattern, while first differences in the other series exhibit positive autocorrelation. [21] The various price series are borderline cointegrated in our data. Though the ADF test statistics based on residuals from OLS regressions that include a constant term and time trend generally do not lead to rejection of the null hypothesis of non-stationarity,[22] the coefficients of the

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[19] In fact, during out sample period, 1986-1990, the correlation between spot WTI crude oil prices and U.S. GNP growth is not statistically significant.

[20] Lags up to 10 weeks and a constant term and time trend were included. For crude oil, spot gasoline and terminal prices the test statistics are respectively -3.06, -3.09, and -2.73, smaller in magnitude than the 5% critical value of -3.43. For semi-monthly retail gasoline prices, the test statistic (with 5 lags, including a dummy variable for odd or even survey, and the same time trend as weekly data) was -2.77 compared to the 5% critical value of -3.82. So in all cases the null hypothesis of a random walk with drift is not rejected.

[21] The first four order correlation coefficients for first differences in terminal price (weekly) and retail gasoline price (semi-monthly) are respectively 0.52, 0.32, 0.21, 0.02, and 0.45, 0.23, 0.04 and -0.04.

[22] For spot gasoline on spot crude oil, terminal on spot crude oil, and terminal on

lagged residual are quite large in magnitude, ranging from -.11 to -.42 in the various cointegration tests. We therefore proceed under the assumption that the price data are cointegrated.

III.3 Asymmetric Retail Price Responses to Crude Oil Price Changes

We estimate equation [8] (as adjusted in appendix A) using semi-monthly retail prices and weekly crude oil prices from 1986 through 1990, both expressed in cents per gallon.[23] The regression results are shown in Appendix C. From the parameter estimates in Appendix C, we construct the cumulative adjustment function for a one cent per gallon change in crude oil prices. The cumulative adjustment function takes into account both the estimated response parameters and the error correction effect. Its exact construction is documented in Appendix B. The results are presented in figure 3.

Figure 3 displays separately the estimated cumulative proportional adjustments to increases and decreases in crude oil prices.[24] Figure 3 indicates that retail gasoline prices adjust more quickly to increases than to decreases in crude oil prices. There are many possible tests of this hypothesis. Strictly speaking, symmetry implies that $\beta_i = \gamma_i \ \forall \ i$, which is rejected at the 1% level. This, however, is a very strict interpretation of the question of asym-

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spot gasoline, the ADF test with lags to 10 weeks are respectively -3.28, -3.14 and -4.71 compared to a 5% critical value of -3.82. For retail gasoline on spot crude oil using semi-monthly data, we additionally include a dummy for odd or even survey. The ADF statistic, with changes in residuals to 5 lags, is -3.27 compared to a 5% critical value of -4.20.

[23] We also tried including monthly seasonal variables to control for seasonality in the rate of change of retail prices. These variables were not jointly significant and their inclusion had almost no effect on the estimated adjustment rates.

[24] These results are from data that are not deflated by a price index. This will not bias the results, because the constant term captures any systematic drift on average, and price inflation was relatively constant throughout this period. We have also carried out the estimation with the data deflated using a weekly consumer price index – interpolated from the government's monthly c.p.i. – with nearly identical results.

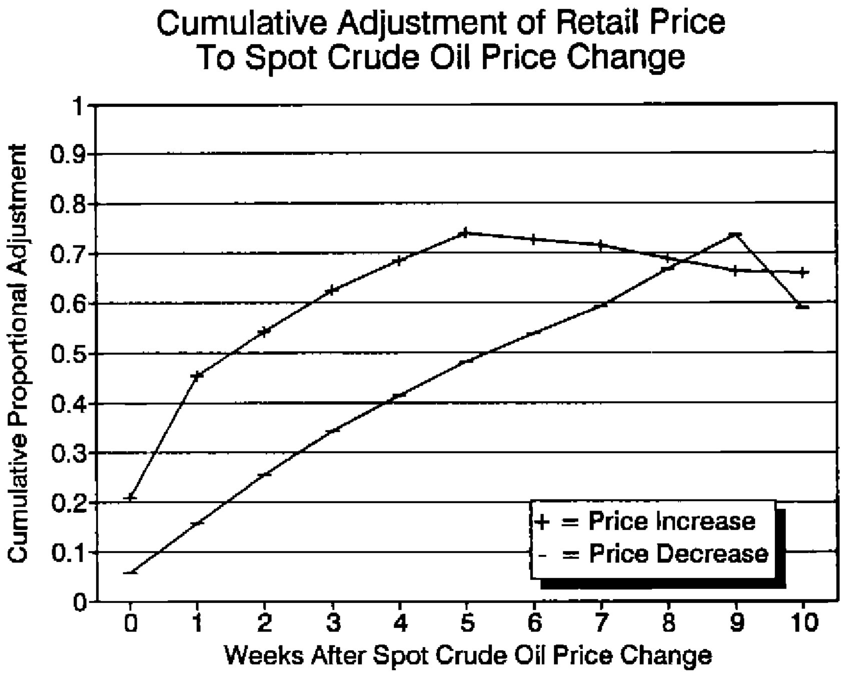

Figure 3

metry and is not particularly informative about the underlying issue of whether such an asymmetry affects consumer costs. Alternatively, we can compare the gain to consumers from a given decrease in crude oil prices over the lifetime of the retail price adjustment with the loss to consumers during the adjustment process from an equal size increase in oil prices.

For instance, a one cent per gallon increase in the price of oil is estimated to increase gasoline prices by 0.21¢ during the week of the crude oil price increase (week 0), while a one cent per gallon decrease in the price of crude is estimated to decrease gasoline prices by 0.06¢ during the same period. Thus, in the week of the crude oil price change, a consumer's costs would increase by 0.13¢ more per gallon when crude prices increase than her costs would decrease when crude prices decrease. Similarly, in week 1, the difference would be 0.45¢ − 0.16¢ = 0.29¢ per gallon. Under the simplifying assumption that consumption is uniform over the period of adjustment, the sum of the differences in cumulative proportional adjustment over the life of the adjustment is an estimate of the asymmetry in cost to the consumer per one cent change in crude prices for each gallon of weekly consumption. That is, the asymmetric adjustment process has a net cost to consumers through week n of

$$\Delta \text{ Consumer Cost} = \sum_{j=0}^{n}(B_j - G_j) \qquad [9]$$

per gallon consumed each week, where B_j and G_j are the cumulative responses through week j to a one cent increase and decrease, respectively, in crude oil price.[25] Equality of the right-hand expression to zero is a nonlinear restriction, because the cumulative adjustment function is a nonlinear function of the estimated parameters, as explained in appendix B. The empirical distribution of this statistic can be estimated with a bootstrap method. We do this, determining the distribution of the measure of asymmetry defined in [9] based on 1000 bootstrap regressions of equation [8]. Rejection of this restriction would indicate that the total cost increase to consumers from an increase in crude oil costs is not equal to the total consumer cost decrease from an equal size decrease in crude oil prices over the life of the adjustment.

Such a comparison raises the question of the appropriate window over which the gains and losses should be compared, *i.e.*, the choice of n. The problem is analogous to the choice of the event window in a stock market

[25] Equation [9] is approximately the difference in the areas under the two cumulative adjustment curves from week 0 to week n.

event study: if the window chosen is too small it will fail to capture the full effect of adjustment, but if it is too large the noise will make it difficult to identify the actual adjustment processes and whether they differ. Unfortunately, the theories discussed in the following section do not suggest a natural window over which the asymmetry hypothesis should be tested. We present tests based on the adjustments through week 5 and week 10. The latter is chosen because we estimate the lag responses out to 10 weeks, and we assume that all significant short-run adjustments are completed by this time. Estimates of the asymmetry through week 10 will probably be unbiased, but they are likely to be noisy. Tests based on adjustment through week 5 are likely to be much less noisy, but may reflect incomplete adjustments in some cases and thus may be biased.

Assuming that the cumulative adjustment is significantly asymmetric only through week 5, the results presented in figure 3 imply a total cost asymmetry of about 1.54¢ per one cent change in crude oil prices for every gallon the consumer buys per week. This difference is significant at the 1% level. Thus, if a consumer uses 10 gallons of gasoline per week,[26] a 5¢ per gallon increase in crude oil prices (equivalent to a $2.10 per barrel crude oil price increase) costs the consumer $0.77 more than a 5¢ per gallon decrease saves her through week 5 of the adjustment. The total cost asymmetry through week 10 is 1.88¢ per one cent change in crude oil price for every gallon the consumer buys per week (also significant at 1%), implying that a 5¢ per gallon increase in crude oil costs the average consumer $0.94¢ more than a similar size decrease would save her. The asymmetry implies that variability in crude oil prices, even if there is no systematic increase or decrease in price, is costly to consumers.

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[26] This is about the U.S. average per vehicle during our sample period. Energy Information Administration (1991), p. 7.

The fact that the asymmetric adjustment process indicates greater costs for consumers than would occur with symmetric adjustment does not imply either market power or supernormal profits among sellers at any point of the production process. Although two of the hypotheses discussed in the next section suggest that temporary market power could explain the asymmetry, other explanations consistent with competitive markets are also plausible.

Finally, it is worth noting that the 10-week transmission of an x cent change in the price of a gallon of crude oil is less than x cents. This sort of incomplete adjustment over the 10 weeks reoccurs in many of our subsequent estimates of price transmission through the points of distribution. In this case, it could be attributed to the fact that there is substitution in inputs and outputs in the refining process, but that explanation is less convincing in explaining the incomplete adjustment of retail or terminal prices to gasoline commodity prices. The scope for substitution is extremely small in those cases, but similar incomplete adjustments are estimated.

At least two other explanations are possible. First, the transmission we observe could reflect only the short-run adjustment to the upstream cost change. If the short-run supply curve is upward sloping, we would expect only partial transmission of a price change over the period observed. For instance, an increase in oil prices might be partially passed along to terminal prices in the short run, but also lead to losses among some or all refiners. As refiners exit the market, price would rise further in the long run, which we would not observe in a 10-week adjustment. An alternate, but related explanation is that the downstream industry under observation experiences industry diseconomies of scale, so that the industry supply curve downstream is upward sloping even in the long run. In that case, the adjustment we observe could be all that actually occurs.

IV. Explanations for Asymmetric Retail Price Adjustments

We have identified three hypotheses that might explain departures from symmetric responses of retail gasoline prices to changes in crude oil prices. These hypotheses differ in the assumed degree of economic sophistication of the agents and in the incentives that the agents are assumed to face. They also differ in the competitive structure that is assumed at various points along the distribution chain. Most importantly, they differ in their implications for selling margins at different points in the distribution chain. These differences yield the predictions that could enable us to differentiate among them.

Hypothesis 1: Prices are sticky downward, because when input prices fall, the old output price offers a natural focal point for oligopolistic sellers. In response to a negative cost shock, a firm might choose to maintain a prior price until demand conditions force a change. Consider a slight modification of Tirole's (1988) price-setting version of the Green and Porter (1984) oligopoly model. There are two firms, $k = i, j$. Let p_0^k be the price that firm k was charging before a cost shock that lowers both firms' constant marginal cost from c_0 to c_1. Demand at firm k is stochastic: $q_t^k = F^k(p^i, p^j)\Theta_t^k$, where Θ is a random variable. Moreover, the firms' products are close substitutes, so that a small price change by one firm induces a large change in the other firm's demand. Each firm observes only its own price and its own demand.

Suppose that there is a probability α that demand falls to a level that would cause each firm to set a competitive (Nash equilibrium) price, p_c^k, whether or not other firms are charging the higher old price. The incentive to lower price may be the result of a perceived change in the gains from cooperation, or a consequence of myopic behavior induced by reduced cash flow. Call this threshold level $\bar{q}^k$. When demand falls below a firm's threshold, the firm cannot determine whether this is the result of a market shock Θ or a low price charged by its rival. If both firms charge the old price, p_0^k, firm i makes an expected profit:

$$V^i(p_0^i, p_0^j) = \pi^i(p_0^i, p_0^j) + \beta(1-\alpha)V^i(p_0^i, p_0^j) + \beta\alpha V^i(p_c^i, p_c^j), \qquad [10]$$

where $V^i(p_c^i, p_c^j) = \pi^i(p_c^i, p_c^j)/(1-\beta)$, the present value of profits when both firms set competitive prices, $\alpha = prob\{\Theta_t^k < \frac{\bar{q}^k}{F^k(p_0^i, p_0^j)} \text{for } i \text{ or } j\}$, and β is a discount factor assumed common to all firms. Thus, firm i's profit at the old price is:

$$V^i(p_0^i, p_0^j) = \frac{\pi^i(p_0^i, p_0^j) + \beta\alpha\pi^i(p_c^i, p_c^j)/(1-\beta)}{1-\beta(1-\alpha)}. \qquad [11]$$

For (p_0^i, p_0^j) to be an equilibrium, $V^i(p_0^i, p_0^j)$ must reach a global maximum at p_0^i. Also, to explain the observed pricing behavior, both firms must be opposed to any price different from p_0^i. Firm i would not increase profits by raising p_0^i in response to a negative cost shock, assuming that firm j does not change its price $(\partial\pi^i(p_0^i, p_0^j)/\partial p_0^i < 0)$. If their products are close substitutes, any reduction in price would cause demand at firm j to fall below its threshold, which would cause firm j to set a Nash price. Let $p^{*i} = \arg\max \pi^i(p_i, p_0)$. A price reduction would lower firm i's profits if

$$\pi^i(p^{*i}, p_0^j) + \beta\pi^i(p_c^i, p_c^j)/(1-\beta) < \frac{\pi^i(p_0^i, p_0^j) + \beta\alpha\pi^i(p_c^i, p_c^j)/(1-\beta)}{1-\beta(1-\alpha)},$$

or

$$\beta > \frac{\pi^i(p^{*i}, p_0^j) - \pi^i(p_0^i, p_0^j)}{(1-\alpha)[\pi^i(p^{*i}, p_0^j) - \pi^i(p_c^i, p_c^j)]}. \qquad [12]$$

Given the short time frame of adjustments to cost shocks in this market, it is reasonable to assume that β is close to one (at least during times when the firm's time preference is not constrained by cash flow). In a symmetric market, if $\pi^i(p_c^i, p_c^j) \to 0$, the right-hand side of [10] is at most $\frac{1}{2(1-\alpha)}$, so that [12] would be satisfied if α is not too large.

A main point of this simple model is that even if firms are prone to remain at their old prices following a negative cost shock, there is some probability that firms will experience a negative demand shock that will induce a reversion to competitive pricing. The probability that closely interdependent firms will set prices at competitive levels increases over time. Furthermore, with numerous clusters of interdependent firms, average prices will exhibit a gradual decline toward competitive levels following a negative cost shock.[27]

An oligopolistic coordination equilibrium of the kind described here is consistent with a rapid response of prices to positive cost shocks and a slow response to negative shocks. If the price p_0 represented a normal profit margin, there would be no reason for firms to hesitate in raising prices in response to a positive cost shock.

The theory is sufficiently general that it might describe the price change transmission mechanism from spot crude oil to spot gasoline, from spot gasoline to gasoline sold at the city terminals, or from terminal gasoline to final retail sale. Upon closer scrutiny, however, the theory is very unlikely to describe the transmission of crude oil price changes to changes in the spot gasoline market. The spot gasoline market is close to perfectly competitive with hundreds of well-informed buyers and sellers. Although transaction prices are not posted per se, they are constantly monitored

[27] The decline in price over time could be gradual for the market as a whole, but not for any particular firm or cluster of independent firms.

and they necessarily track the prices for gasoline futures, which are traded on the NYME, quite closely.[28] Sellers on the gasoline spot market must consider themselves price takers, so the theory would not be applicable.

The oligopolistic coordination theory could possibly explain asymmetric terminal price movements in response to spot gasoline or crude oil price changes, if such an asymmetry exists. In fact, this seems to be the implication of complaints that the oil refining companies collude to slow passthrough of oil price decreases. There is, however, an important check on oligopolistic coordination in the sale of even branded product at the terminals. If a refiner's branded price at the terminal gets too high relative to the spot price from gasoline, the refiner will quickly see two effects: (1) it will lose most or all sales for use other than branded resale, *i.e.*, marginal sales on which it competes with unbranded gasoline, and (2) branded resellers of the refiner's product, jobbers and retailers, will suffer reduced margins or reduced sales and will pressure the refiner to lower its price.

The theory seems most likely to describe the reaction of retail prices to changes in the wholesale or terminal price. Sellers are spatially and otherwise differentiated. They face many competitors, only some of which they can monitor at low cost. If stations in an area are operating at competitive margins and then the wholesale price of gasoline declines, it seems plausible that each station might maintain its retail price until it sees convincing evidence (in the form of lower sales) that competing stations have lowered price. The sellers are certainly not price takers, and the buyers are not completely informed about the price of each seller.[29]

Hypothesis 2: Production lags and finite inventories of gasoline imply that

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[28] See Ng and Pirrong (1992).

[29] See Shepard (1991a) and Borenstein (1991) for evidence of price discrimination and local market power among retail gasoline sellers.

negative shocks to the future optimal gasoline consumption path can be accommodated more quickly than positive shocks. If half of all world oil reserves suddenly disappeared, the long run competitive price of gasoline would increase greatly and consumption would decrease greatly. Oil companies could accommodate that change quickly by raising gasoline prices. Since refinery production schedules cannot be adjusted immediately – such responses generally take at least 2 to 4 weeks to implement – the result would be a short run building up of finished gasoline inventories. In contrast, if world oil reserves doubled overnight the short run response in the gasoline market would be limited by available supplies of finished gasoline. Essentially, this argument relies on an asymmetry between the short run cost of decreasing inventories versus increasing inventories. While it is clear that inventories must be non-negative so the cost of decreasing inventories must increase substantially at some point, the elasticity of the marginal cost of increasing inventories is less clear. If, for instance, storage adjustment marginal costs were decreasing at low levels of reserves and constant at all higher levels, as would be the case if refiners had substantial excess storage capacity, then the asymmetry in storage adjustment costs would exist.

Reagan and Weitzman (1982) present such a model with asymmetric inventory adjustment costs due to the non-negativity constraint on inventories. They find that in the short run prices should respond more to situations of excess demand than to excess supply, because the ability and incentive for competitive firms to respond with inventory (quantity) adjustments is greater in the case of excess supply. Bresnahan and Spiller (1986) develop a related theoretical model that explains "backwardation," the premium of spot prices over futures prices. They note that arbitrage constrains the amount by which futures prices can exceed current spot prices (known as a "contango" condition, the opposite of backwardation), because all current consumption can be shifted into the future. By contrast, the only future consumption that can be shifted to the current period – the arbitrage that would limit backwardation – is the current inventories that otherwise would be held to the next.

Over the period of our dataset, U.S. reserves of finished gasoline fluctuated between 21 and 31 days of contemporaneous consumption. Whether there is an asymmetry in inventory adjustment costs and whether it is likely to have a non-trivial effect on prices when inventories are within this range are empirical questions that we hope to address in future work.

This inventories theory could explain asymmetry in the adjustment of spot (or futures) gasoline prices to spot (or futures) crude oil prices or in the adjustment of terminal prices to the upstream spot prices. It is unlikely to be relevant to an asymmetry that could occur between terminal price and retail price changes, because service stations do not generally set price in order to ration scarce inventories. Service stations can almost always order and receive delivery of gasoline on less than 48 hours notice.[30]

Hypothesis 3: Volatile crude oil prices create a signal-extraction problem for consumers that lowers the expected payoff from search and makes retail outlets less competitive. When a consumer knows that crude oil prices or retail gasoline prices are currently volatile, he or she may be more likely to believe that an increase in one station's retail price reflects crude oil price changes, rather than a change in the station's relative price in the retail market. Thus, the expected gain from search in reaction to a retail price increase may be smaller when crude oil prices are known to be volatile than when they are fairly stable. Each retailer realizes that this implies a

[30] At least two major refiners we have spoken with say that they set no minimum quantity for delivery to their branded stations, though one does require that the stations it delivers to have underground storage tanks of at least a minimum size, and it is customary for a station to order sufficient quantity to fill its tanks. The most active stations receive deliveries every few days, while those selling less volume may get supplied only every one to two weeks.

temporary decline in the elasticity of demand it faces and thus increases its margin. This temporarily increased market power of retailers may dampen the rate of passthrough of upstream price decreases and exacerbate the rate of passthrough of upstream price increases, possibly even resulting in temporary "overshooting" on increase. Since this is a theory of costly search it applies to retail margins, but has little to say about refiner or wholesaler margins.

Bénabou and Gertner (1991) formalize a theory of costly endogenous search and conclude that common cost shocks among competing firms (or economy-wide inflation) can increase or decrease the equilibrium amount of consumer search, and thus increase or decrease competition among sellers. They find that search is more likely to decrease due to common cost shocks if the cost of search is high to begin with.

These three hypotheses do not exhaust the possible explanations for the asymmetric response of retail gasoline to crude oil prices. Still, variations on these theories have been suggested either directly in the context of gasoline pricing, as is the case for hypothesis #1, or more broadly, but with obvious application to the gasoline market, *e.g.*, hypotheses #2 and #3. Recognizing that we will not in this study be able to identify the single model that describes the actual transmission process from crude oil to retail gasoline prices, we seek instead to narrow the field by ruling out common explanations that are not supported by a more detailed analysis of the data.

V. Identifying the Asymmetric Transmission of Price Responses

The first price transmission we investigate for asymmetry is from changes in crude oil prices to changes in the commodity price for generic gasoline. The spot and futures gasoline markets are used by independent refiners and marketers of gasoline to obtain and sell gasoline, as well as by firms interested in hedging risk or speculating on future shocks to gasoline demand or supply. It is also used by the major refiners to balance excess supply or demand for their branded product. With the proper additives and the appropriate insignia on the side of the delivery truck, generic gasoline bought in the spot market can be marketed as gasoline of a major refiner.

The large number of participants in the gasoline spot and futures markets, and the generic nature of the product, make these markets quite competitive. Since the refined gasoline product is traded in these markets, price will reflect not only the cost of inputs in making gasoline, particularly crude oil, but also the short run constraints on delivery due to the availability of gasoline inventories. If asymmetric inventory adjustment costs, as explained in hypothesis #2, are responsible for the asymmetry of retail price adjustment to crude oil price changes, one might expect this to be evident in the relationship between the spot gasoline price and spot crude oil prices. Hypotheses #1 and #3 would not be supported by an asymmetry in spot gasoline price adjustment, because of the low search costs and competitiveness in the spot gasoline market.

The estimates, represented in figure 4, exhibit an asymmetry in the response of gasoline spot prices to changes in crude oil spot prices. The asymmetry is 1.80¢ after 5 weeks (per one-cent change in crude oil spot price) and is statistically significant at the 1% level. It is 1.36¢ after 10 weeks, but it is significant at only the 8% level.[31]

The adjustment of generic gasoline prices to changes in crude oil prices appears to occur very quickly and the cumulative adjustment is fairly sym-

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[31] We have also estimated this adjustment function using daily data and have found very similar results.

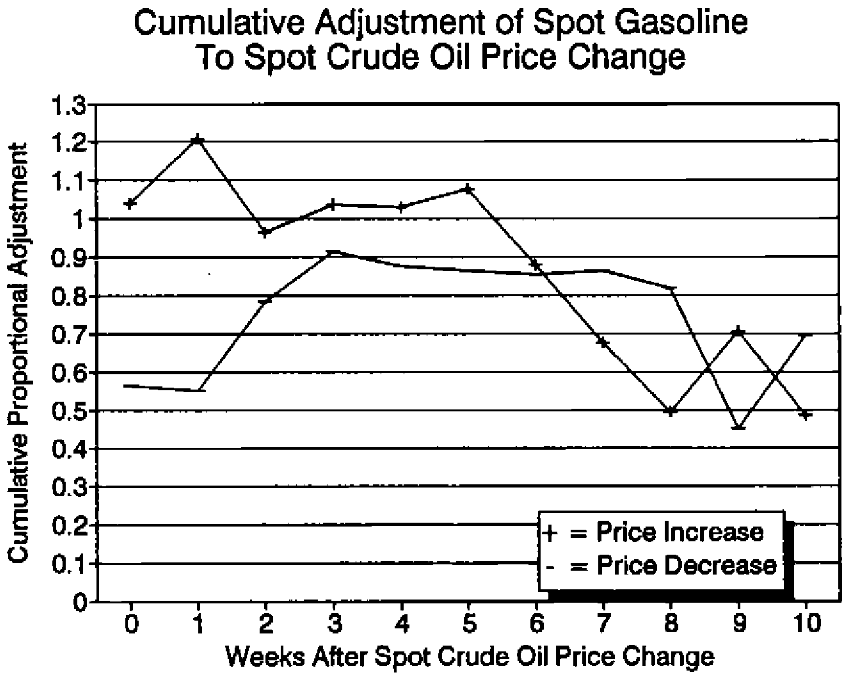

Figure 4

metric at the end of week 2.[32] In the first two weeks, however, there is a significant asymmetry. One might wonder, however, whether this might be an artifact of the spot price data collection.[33] To check this, we compared the results to those using the one-month ahead futures price series and found very similar results.

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[32] The cumulative adjustments to increases and decreases are not significantly different at the 5% level in any week after week 1. These tests are not independent week to week, but they do provide a guidepost for analyzing the estimated differences.

[33] Ng and Pirrong (1992) find that new information in refined petroleum product markets generally affects prices in the futures market before it appears in the spot market. The lag they find, however, is only about 2 days.

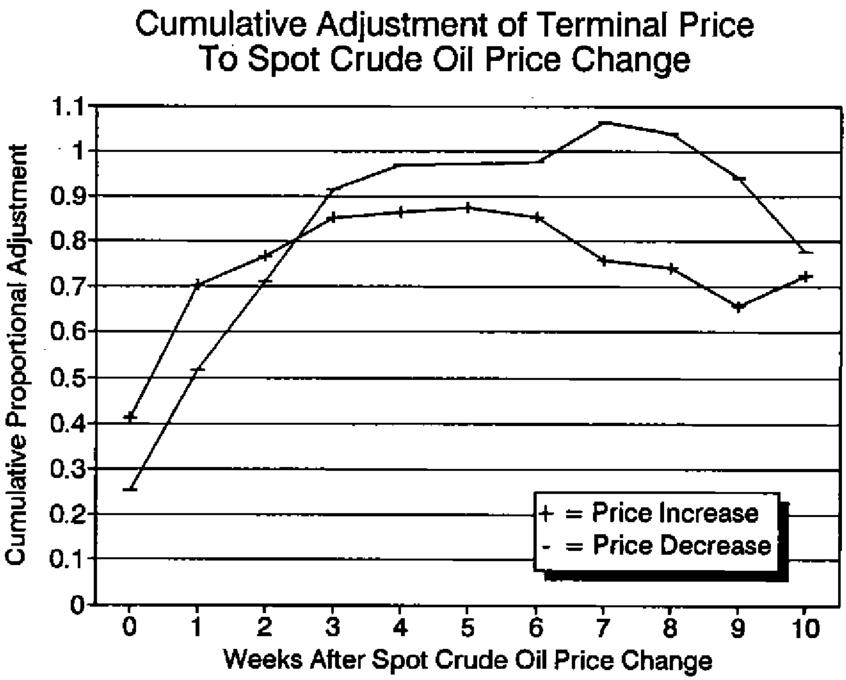

Figure 5

These results appear to violate weak form efficiency in the spot or futures unleaded gasoline markets. It appears that the change in today's crude oil price can be used to predict next week's change in the unleaded gasoline commodity price. Though this interpretation is correct, it may not be possible to trade profitably on this information. The reason again relates to the level of inventories and the marginal cost of changing inventory levels. If gasoline inventories are low, then a decrease in crude oil prices might not be immediately transmitted downstream because the very short run scarcity value of the gasoline exceeds its eventual replacement cost. Arbitraging may not be possible because the higher short-run price reflects the temporary

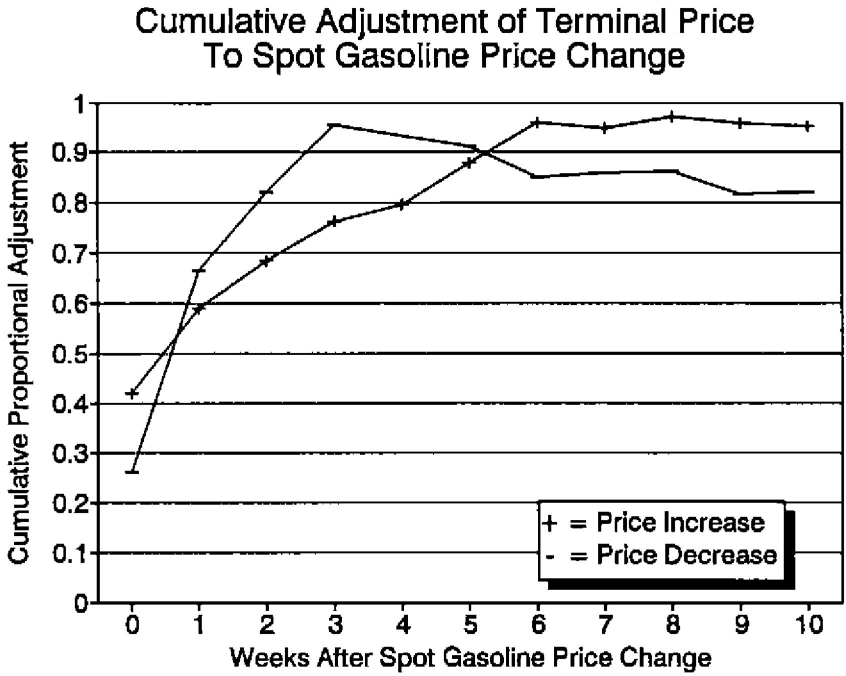

Figure 6

scarcity.

The brief asymmetry in the gasoline commodity price response to crude oil price changes is probably part of the cause for the asymmetric response of retail prices to crude oil price changes. It is consistent with the theory that asymmetries in inventory response costs explain part of the retail price response. There are other possible interpretations, but in any case, this component of the explanation cannot be attributed to hypotheses #1 or #3.

Is the spot gasoline response asymmetry the entire explanation for the retail price response asymmetry to crude oil price changes? Probably not for at least two reasons. First, the retail price asymmetry is significant at 5% until week 7 and is of much larger magnitude than the asymmetry in spot gasoline response to crude oil prices at every point between weeks 2 and 6. If all downstream responses to spot gasoline markets were symmetric, then any asymmetry in the reaction of downstream gasoline markets to crude oil would be insignificant after the second week.

Second, figure 5 indicates that whatever asymmetry is present in the response of spot gasoline prices to crude oil prices, it is much weaker in the response of terminal prices to crude oil prices. Based again on the type of regression and cumulative adjustment function explained in section III, figure 5 indicates that terminal prices do not increase more quickly than they decrease in response to crude oil price changes. Though there is a slight asymmetry in the first two weeks that probably reflects the response of spot gasoline to crude oil price changes, the estimated cost asymmetry in the response of terminal prices to crude oil prices is 0.13¢ over the five weeks and statistically insignificant. It is negative, −0.94¢, at ten weeks, but also not significant. The adjustment of terminal prices to crude price changes appears to be largely complete in 3 weeks.

The reason that terminal prices do not show the asymmetry in responding to crude oil that spot gasoline does is in part attributable to the response of terminal prices to spot gasoline price changes, as shown in figure 6. Terminal prices appear to adjust more quickly to declines in the spot gasoline price than to increases. The 5-week cost asymmetry difference is −0.41¢ and is significant at 7%. The ten-week difference is 0.17¢ and not statistically significant. The explanation for a "reverse" asymmetry through week 5 is not immediately apparent, but its magnitude is also relatively small compared to the asymmetries between retail or spot gasoline

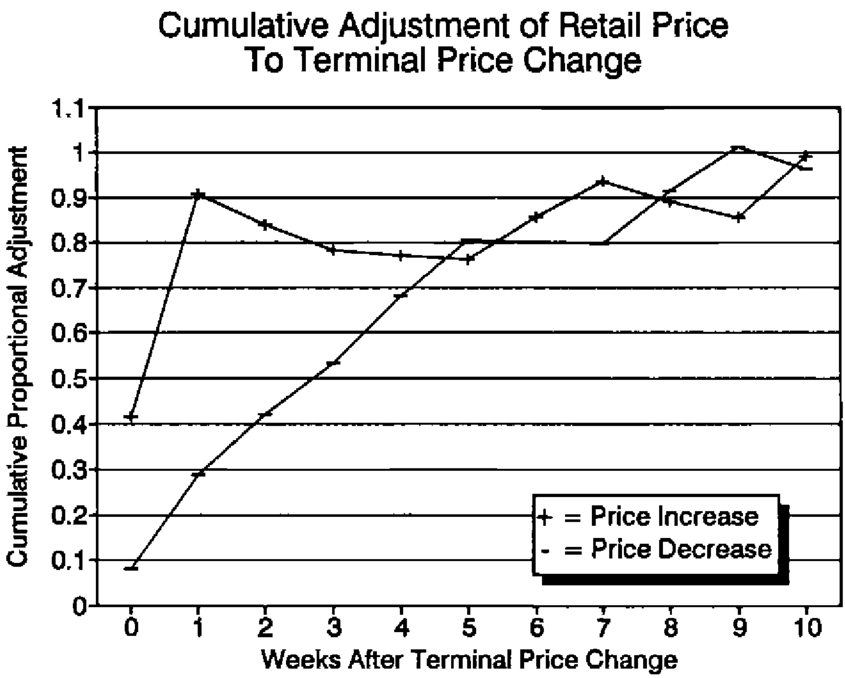

Figure 7

and crude oil.

The results presented in figures 5 and 6 conflict with hypothesis #1 to the extent that it might explain an asymmetry in the price adjusting behavior of the major refiners. If crude oil price decreases facilitated coordination among the major refiners of gasoline that induce the retail price asymmetry described in section III, then transmission of changes from crude oil prices to terminal prices would be expected to exhibit that asymmetry.

The most significant source of the retail price response to spot crude oil price changes seems to be in the transmission process from terminal to retail prices. Figure 7 indicates that terminal price increases are transmitted to retail prices significantly more quickly that terminal price decreases. The cost asymmetry is estimated to be 1.67¢ at five weeks for every one cent change in the terminal price (significant at 1%) and 1.71¢ at ten weeks (significant at 1%).[34] The estimates are about the size of the estimated overall asymmetry in retail gasoline price responses to crude oil price changes. Increases in terminal prices are mostly transmitted to retail prices by the first or second week after the the terminal price rise. Decreases in terminal prices, however, are passed through to retail gradually over the following 9 weeks.

The pattern of the retail-terminal asymmetry is quite different from the retail-crude asymmetry. The retail-terminal asymmetry is more pronounced in the first few weeks, but it disappears statistically by week 4,[35] The retail-crude asymmetry is less striking over the first few weeks, but is statistically present until week 7.

The estimated retail-terminal asymmetry supports hypothesis #1 as it relates to the retail gasoline market and to hypothesis #3, that the consumers' signal-extraction problem resulting from noisy common input prices temporarily lowers the elasticity of demand faced by retail outlets. This may result in retailers increasing prices more quickly and decreasing prices more slowly in response to input price changes than would occur if consumers were perfectly informed.

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[34] Karrenbrock (1991) also finds that retail gasoline prices respond asymmetrically to changes in wholesale prices, though his use of monthly data (from the Energy Information Administration) limits the precision of the estimates regarding the size of the asymmetry.

[35] The cumulative adjustments to increases and decreases are not significantly different at 5% in any week after week 3.

VI. Conclusions

Gasoline prices clearly respond with a lag to crude oil prices changes. This lagged response can be estimated precisely enough that it is possible to identify asymmetric responses to crude oil price increases and decreases. The evidence we have gathered supports the common belief that retail gasoline prices respond more quickly to increases in crude oil prices than to decreases. Establishing the points in the distribution chain at which the asymmetries occur is a powerful tool in distinguishing between the possible explanations for the phenomenon. The response of spot gasoline markets to changes in crude oil prices is responsible for some of this asymmetry, but is short-lived, lasting only about 2 weeks.

The largest source of the asymmetry appears to be the response of retail gasoline to wholesale price changes at the terminal level. At any point in time, wholesale gasoline prices should fully incorporate information about current inventories, so the explanation for the asymmetry in retail adjustment to changes in wholesale gasoline prices must be found elsewhere. This result is consistent with the theoretical work of Bénabou and Gertner (1991), which demonstrates that consumers may search less when the common input prices of all retailers become more variable, causing short run decreases in the elasticity of demand that each retailer faces. It is also, however, consistent with a model of sticky downward price adjustment in an oligopoly with imperfect monitoring. In further work, we hope to be able to distinguish between these and other possible explanations.

Appendix A: Adjustments for Inconsistent Periodicity of Retail Price Data

As explained in the text, the time between retail price surveys is usually two weeks, but is three weeks in about 15% of the observations. In all regressions in which retail price is the dependent variable, however, the explanatory variables are still observed every week. So, we can still theoretically recover the adjustment parameters for every week after the crude oil price change. The weekly change model in [5] can be written as:

$$R_t - R_{t-1} = \sum_{i=0}^{n} (\beta_i \; \Delta C^{+}_{t-i} + \gamma_i \; \Delta C^{-}_{t-i}) \qquad [A1.1]$$

or

$$R_{t-1} - R_{t-2} = \sum_{i=0}^{n} (\beta_i \; \Delta C^{+}_{t-i-1} + \gamma_i \; \Delta C^{-}_{t-i-1}) \qquad [A1.2]$$

or

$$R_{t-2} - R_{t-3} = \sum_{i=0}^{n} (\beta_i \; \Delta C^{+}_{t-i-2} + \gamma_i \; \Delta C^{-}_{t-i-2}). \qquad [A1.3]$$

So, if there is a two-week gap between observations of retail price, summing [A1.1] and [A1.2] gives

$$R_t - R_{t-2} = \sum_{i=0}^{n} \{\beta_i(\Delta C^{+}_{t-i} + \Delta C^{+}_{t-i-1}) + \gamma_i(\Delta C^{-}_{t-i} + \Delta C^{-}_{t-i-1})\}. \quad [A2.1]$$

If there is a three-week gap between observations, then summing [A1.1], [A1.2], and [A1.3] gives

$$\begin{aligned} R_t - R_{t-3} = \sum_{i=0}^{n} \{ & \beta_i(\Delta C^{+}_{t-i} + \Delta C^{+}_{t-i-1} + \Delta C^{+}_{t-i-2}) \\ & + \gamma_i(\Delta C^{-}_{t-i} + \Delta C^{-}_{t-i-1} + \Delta C^{-}_{t-i-2})\}, \end{aligned} \qquad [A2.2]$$

where the β_i and γ_i parameters estimated in [A2.1] and [A2.2] are the same weekly adjustment parameters.

Allowing for the asymmetry and estimating the adjustment relationship [A2.1]/[A2.2] out to 10 weeks implies estimation of over 20 parameters on a dataset that includes 119 observations after differencing. For parsimony, we estimate the adjustment rates by imposing the restrictions $\beta_0 = \beta_1$, $\beta_2 = \beta_3$, etc., and similarly for the γ's. The data do not reject this constraint at even the 30% level, possibly due to the low power of the hypothesis test, and it reduces by 10 the number of parameters to estimate.

When we include an error correction term and adjust for the fact that the first survey of each month includes a different set of cities than the second survey, we actually estimate retail price changes from:

$$\begin{aligned} R_t - R_{t-j} &= \theta_0 + \sum_{i=0}^{n}\{\beta_i \sum_{k=0}^{j-1}(\Delta C^{+}_{t-i-k}) + \gamma_i \sum_{k=0}^{j-1}(\Delta C^{-}_{t-i-k})\} \\ &+ \theta_1 \sum_{k=0}^{j-1}(\hat{\alpha}^k)(R_{t-j} - \hat{\phi}_0 - \hat{\phi}_1 C_{t-j} - \hat{\phi}_2 WK_{t-j} - \hat{\phi}_3 SRV2_{t-j}) \\ &+ \theta_2 SRV2_t \end{aligned} \qquad [A3]$$

where j is the number of weeks between the survey that occurred at time t and the previous survey, $SRV2_t$ is a dummy variable equal to one if the survey at time t is the second survey of the month, WK_t is a time trend, θ_1 is the estimated error correction parameter, the $\hat{\phi}$ parameters are estimated from a previous regression of R_t on a constant, C_t, $SRV2_t$, and WK_t, and $\hat{\alpha}$ is an estimated parameter to adjust the error correction effect for the inconsistent periodicity of observation, as explained below. As mentioned previously, we restrict every $\beta_i = \beta_{i-1}$ and $\gamma_i = \gamma_{i-1}$ if i is an odd number.

Inclusion of an error correction term in the regression raises further estimation issues because of the infrequent retail price data periodicity. For $j = 2$, the error correction term should involve both R_{t-1} and R_{t-2}, but data on R_{t-1} are not available. Defining $\hat{\phi}X_t = \hat{\phi}_0 + \hat{\phi}_1 C_t + \hat{\phi}_2 WK_t + \hat{\phi}_3 SRV2_t$, the error correction term $\theta_1\{(R_{t-1} - \hat{\phi}X_{t-1}) + (R_{t-2} - \hat{\phi}X_{t-2})\}$

is approximated by $\theta_1(1+\hat{\alpha})(R_{t-2} - \hat{\phi}X_{t-2})$, imposing the restriction that $(R_{t-1} - \hat{\phi}X_{t-1}) = \alpha(R_{t-2} - \hat{\phi}X_{t-2})$. For $j = 3$, the approximation is $\theta_1(1+\hat{\alpha}+\hat{\alpha}^2)(R_{t-3} - \hat{\phi}X_{t-3})$. The coefficient $\hat{\alpha}$ is estimated by the regression $(R_t - \hat{\phi}_0 - \hat{\phi}X_t) = \alpha^j(R_{t-j} - \hat{\phi}X_{t-j})$, where $j = 2$ or 3. The effect of this approximation will be small if α is close to 1. In all the retail regressions for which we report results in this paper, $\hat{\alpha} \geq 0.8$.[36]

[36] Alternatively, we can write [8] as a function $R_t = f(R_{t-1})$, lag the equation and substitute for R_{t-1} to give $R_t = g(R_{t-2})$, and similarly $R_t = h(R_{t-3})$ for surveys three weeks apart. These functions can then be estimated by non-linear least squares. This is a much more cumbersome procedure, but it yields similar results for the response of retail price to crude oil price changes.

Appendix B: Construction of the Cumulative Adjustment Functions

From the parameters in equation [10] or [11], we construct a cumulative adjustment function that represents the response path to a one-cent change in the independent variable that occurs from a point of long-run equilibrium. We describe the construction of the cumulative adjustment function for a one-cent increase, but the process is the same for a one-unit decrease with γ substituted everywhere for β.

The period 0 adjustment is simply the estimated β_0. The relationship had been in long-run equilibrium at time 0, so there is no error correction effect. For all later periods i, the marginal adjustment is the estimated β_i plus the estimated error correction effect. The error correction at any time t is expected to be the estimated error correction parameter, $\hat{\theta}_1$ multiplied by the difference between the cumulative adjustment at the beginning of the period and the long run estimated adjustment to a one unit change in the independent variable, ϕ_1.

$$\begin{aligned}
B_0 &= \hat{\beta}_0, \\
B_1 &= B_0 + \hat{\theta}_1(B_0 - \hat{\phi}_1) + \hat{\beta}_1, \\
B_2 &= B_1 + \hat{\theta}_1(B_1 - \hat{\phi}_1) + \hat{\beta}_2, \\
\vdots \quad & \quad \vdots \\
B_{10} &= B_9 + \hat{\theta}_1(B_9 - \hat{\phi}_1) + \hat{\beta}_{10}.
\end{aligned} \qquad [B1]$$

Appendix C: Retail Adjustment to Crude Oil Price Changes

Dependent Variable: Retail Change

Total Observations: 119

$R^2 = 0.683 \quad \bar{R}^2 = 0.640$

$SSR = 398.43 \quad SEE = 1.957$

Durbin-Watson Statistic = 1.650

Variable	Coefficient	Std. Err.	T-statistic
Constant	-1.866	0.451	-4.13
ΔCrude$+_0$	0.209	0.048	4.37
ΔCrude$+_1$	0.209	0.048	4.37
ΔCrude$+_2$	0.071	0.064	1.11
ΔCrude$+_3$	0.071	0.064	1.11
ΔCrude$+_4$	0.052	0.069	0.75
ΔCrude$+_5$	0.052	0.069	0.75
ΔCrude$+_6$	-0.012	0.064	-0.19
ΔCrude$+_7$	-0.012	0.064	-0.19
ΔCrude$+_8$	-0.028	0.052	-0.54
ΔCrude$+_9$	-0.028	0.052	-0.54
ΔCrude$+_{10}$	0.007	0.092	0.08
ΔCrude$-_0$	0.057	0.048	1.17
ΔCrude$-_1$	0.057	0.048	1.17
ΔCrude$-_2$	0.058	0.053	1.09
ΔCrude$-_3$	0.058	0.053	1.09
ΔCrude$-_4$	0.045	0.050	0.91
ΔCrude$-_5$	0.045	0.050	0.91
ΔCrude$-_6$	0.040	0.048	0.83
ΔCrude$-_7$	0.040	0.048	0.83
ΔCrude$-_8$	0.066	0.049	1.33
ΔCrude$-_9$	0.066	0.049	1.33
ΔCrude$-_{10}$	-0.147	0.088	-1.67
$SRV2$	2.919	0.372	7.84
$ERRCORR$	-0.067	0.023	-2.84

$SRV2$ is a dummy variable equal to 1 if the observation is the second survey of the month.

$ERRCORR$ is the one period lagged residual from the estimated long run equation:

$$R_t = 33.4864 + 0.7313428 * C_t + 1.228612 * SRV2_t + 0.03166278 * WK_t$$

where WK_t is a time trend, the week number beginning in January 1986.

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