DO RETAIL GASOLINE PRICES RISE MORE READILY THAN THEY FALL? A THRESHOLD COINTEGRATION APPROACH

Salim Al-Gudhea Turalay Kenc Sel Dibooglu *

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This paper revisits the controversy over whether retail gasoline prices respond to increases in upstream prices more rapidly than decreases. Using threshold and momentum models of cointegration and daily data at different stages in the distribution chain, we find that transmission between upstream and downstream prices is mostly asymmetric in the momentum model: increases in upstream prices are passed on to downstream prices more quickly than decreases. We distinguish between small and large shocks and show that the asymmetry is more pronounced for small shocks, which may be due to consumer search costs.

Keywords: Asymmetric adjustment, gasoline prices, time series models.

JEL Classification numbers: L11, Q40.

*AlGudhea: Saudi Arabian Monetary Agency, Riyadh, Saudi Arabia. Kenc: The Business School, Imperial College London, Direct Line: +44-20-7594 9212, Fax: +44-20-7823 7685, Email: t.kenc@ic.ac.uk. Dibooglu: Department of Economics, University of Missouri - St. Louis, One University Blvd., St. Louis, MO 63121, Direct Line: +1-314-516 5530, Fax: +1-314-516 5352 Email: dibo@siu.edu.

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1 Introduction

The recent surge in gasoline prices necessitates another look at the retail gasoline market in the United States. Even though the crude oil price is a principal determinant of the retail gasoline price, it is not the only one[1]. There are several steps in the transmission from the crude to the retail level and the margins may also affect retail price developments[2]. Some observers claim that there is an inconsistency in the movements of the crude oil price and retail gasoline prices and that retail gasoline prices respond asymmetrically to crude oil price changes: even when the price for crude oil falls, it is claimed that gas stations keep advertising high gasoline prices for a few days.

Common explanations of asymmetry include market power, accounting practices, collusive behavior, search costs, inventories, and consumer response to changing prices; see, Brown and Yucel (2000). Consumer responses to changing prices can accelerate price increases but not decreases. After an an initial increase in crude oil price, consumers see the increase reflected in the retail gasoline price and expect higher prices the next day. This prompts a quick response of higher demand with the hope that prices will be lower when the next filling is due. Such behavior will accelerate the increase in retail prices of gasoline. On the other hand, if retail prices are decreasing, consumers may expect the decrease to go on in the coming few days,

[1]Indeed, the simple correlation coefficient between the daily percentage changes of the retail gasoline price and the crude oil price is a mere 2.5 percent in our sample.

[2]The U.S. Energy Information Administration data show that crude oil accounted for only 44 percent of the retail price of a gallon of gasoline in 2003. The rest went to Federal and State Taxes (27 percent), refining costs and profits (15 percent) and distributing and marketing costs (14 percent).

so they prefer to wait until the prices reach their expected lower levels. Inventories can contribute to the asymmetric relationship between the price of crude oil and retail gasoline prices. As Brown and Yucel (2000) emphasize, inventories would buffer downstream price movements less when prices are rising than when they are falling. As the crude price increases (lower supply of crude oil), gasoline inventories decline, which leads to higher retail gasoline prices. In contrast, lower crude oil price (higher supply of crude oil) leads to higher inventories and lower prices of retail gasoline. Brown and Yucel argue that firms tend to incorporate the lower crude price later. Finally, when the crude oil supply declines, refiners tend to lower output quickly to avoid higher adjustment costs. However, when supply of crude oil is abundant, refiners are not pressured to increase output quickly. The latter will result in a slow decline in gasoline prices.

Despite the fact that the nature of the retail gasoline market makes it hard to make a case for an outright market power, limited market power at the local level is plausible. For example, location can afford a gas station limited monopoly power to the extent that consumers are unwilling to engage in a costly search for a lower priced gasoline. A gas station knows that small price changes produce little incentives for a costly consumer search. As Brown and Yucel (2000) observed, the total saving per week for a typical consumer in the U.S. is less than 50 cents when the consumer pays an extra 5 cents/gallon for gasoline. This is hardly an amount that justifies a costly search for a lower priced gasoline when the consumer risks running out of gasoline. With full knowledge of this potential cost difference among competitors, a gas station can afford to wait and not pass the saving to the consumer when crude prices are falling slowly. However, large crude oil price changes can force gas stations to behave in a more competitive way since gas stations are unwilling to risk losing customers. In this case, they are likely to pass the saving to consumers when price differences are likely to justify costly searches by consumers.

Although numerous papers have studied the asymmetric behavior of retail gasoline prices, empirical evidence regarding asymmetry has been mixed: for example, Borenstein, Cameron, and Gilbert (1997) find asymmetric behavior in most downstream prices, but Bachmeier and Griffin (2003) present evidence that retail gasoline price respond symmetrically to crude oil price shocks. Balke, Brown, and Yucel (1998) find the adjustment in gasoline prices to be asymmetric; however, their finding is sensitive to whether the series are in levels or in the first differences. The asymmetry is present in the differenced series, whereas it is absent when using data in levels. Recently, Lewis (2004) developed a consumer search model of asymmetric adjustment and showed that the data are consistent with the predictions of the search model. However, Radchenko (2004) cannot confirm that the asymmetry in gasoline prices is consistent with search theory. Using threshold cointegration methods, Chen, Finney, and Lai (2005) provide supportive evidence for asymmetric adjustment in U.S. retail gasoline prices. Dunis, Laws, and Evans (2005) apply threshold cointegration methods to NYMEX futures contract daily closing prices and unleaded gasoline and find asymmetric adjustment. More recently Grasso and Manera (2006) apply asymmetric error correction models to European data and find evidence of asymmetry for all countries considered, particularly at the distribution stage.

A shortcoming of the existing literature is that it has paid little attention to the size of the shocks to upstream prices. Indeed, a "large" shock may elucidate a completely different response than a typical one, given consumer search costs[3]. Moreover, it is commonly assumed that the effects of a shock to the upstream price can be traced out from the estimated relations without feedbacks from the downstream price. As emphasized by Geweke (2004), it is likely that shocks to downstream prices may also impact upstream prices.

The principal objective of this paper is to reexamine the asymmetric behavior of retail gasoline prices with an emphasis on the *size* of the underlying crude oil price shocks. We consider investigating pairwise asymmetric adjustments between crude oil price (cp) and retail gasoline price (rp), crude oil price and spot gasoline price (sp), spot gasoline price and wholesale gasoline price (wp), and wholesale gasoline price and retail gasoline price. The issue is germane since current gasoline prices are high by historical standards and any sign that the gasoline market is inefficient is of considerable interest. To that end, we use threshold and momentum models of cointegration developed by Enders and Granger (1998) and Enders and Siklos (2001). Since these methods assume nonzero thresholds, they are capable of distinguishing the response of the retail gasoline price to "typical" versus "large" crude oil price shocks. Thus, in a vector error correction framework, above threshold shocks may be corrected in a fundamentally different manner than below threshold shocks. Instead of tracing the response of the retail gasoline price to a $1 crude oil price shock, we contrast the response of the retail price to a "typical" crude oil price shock of historical

[3]For example, in a different framework, Ravn and Sola (2004) show that the size of the monetary policy shocks matter in affecting aggregate economic activity in a menu-cost model.

size, and an "unusually large" crude oil price shock.

To preview our results, we confirm that each pair of prices are cointegrated and adjustments toward long-run equilibria are symmetric in the traditional sense. However, for all pairwise relationships the series exhibit more momentum in one direction than the other; hence asymmetry is prevalent in the momentum model. Moreover, the asymmetry is more pronounced for "typical" shocks as opposed to large shocks at the retail level, which lends some support to the consumer search cost hypothesis.

2 Data and Methodology

We use West Texas Intermediate spot price as our crude oil price. Spot price of gasoline is the average of New York, Gulf Coast, and Los Angeles conventional regular gasoline spot prices, and they are collected on a daily basis and obtained from U.S. Department of Energy, Energy Information Administration. Retail gasoline price is a U.S. average price for regular unleaded retail gasoline. The wholesale price of gasoline is a U.S. average price for conventional area wholesale prices. Wholesale and retail prices are daily data obtained from Oil Price Information Service (OPIS). The data covers the period from December 1998 to January 2004.

When studying the behavior of downstream price responses to changes in the upstream prices of gasoline, consider the following long run relationship between upstream and downstream prices of gasoline:

$$y_t = \beta_0 + \beta_1 x_t + \mu_t \tag{1}$$

where y_t is the downstream price, x_t is the upstream price, μ_t is a stationary random variable that represents the deviation from the long run equilibrium, if any. At which stage the asymmetric behavior emerges can be detected from the pairwise relationships. Before outlining the methodology, we pretest the variables for unit roots and stationarity using Augmented Dickey-Fuller (ADF) and KPSS tests.[4] The ADF test results in Table 1 are inconclusive except for the wholesale price which seems stationary. However, the KPSS test statistics soundly reject null hypothesis of stationarity for all series in levels. Given the treatment of gasoline prices in the literature and the results of the KPSS test, we proceed with the assumption that all price series unit root processes. Even though the cointegration framework is warranted in the presence of unit roots, conventional cointegration tests with linear adjustment are inappropriate if the dynamic adjustment of prices exhibits non-linear behavior.

Consider the Engel and Granger (1987) method of testing for cointegration. The test depends on the OLS estimates of ρ in the following regression:

$$\Delta\mu_t = \rho\mu_{t-1} + \epsilon_t \tag{2}$$

where μ_t is the residual from the estimated regression in equations (1). If $-2 < \rho < 0$, then the upstream and the downstream prices (for example, rp and cp) are cointegrated, which also implies that μ_t in (2) is stationary with mean zero. Note that (2) implies symmetric adjustment. In other words, $\Delta\mu_t$ equals ρ multiplied by μ_{t-1}, regardless of whether μ_{t-1} is positive or negative. According to Pippenger and Goering (1993) and Enders and Granger (1998), the standard tests for unit-roots and cointegration all have low power in the presence of mis-specified dynamics. In our

[4] The ADF critical values can be found in Fuller (1976); for the KPSS test and critical values, see Kwiatkowski, Philips, Schmidt, and Shin (1992).

case, this is important since the linear relationship in equation (1) is inappropriate if, for example, retail prices of gasoline rise faster when there is an increase in the price of crude oil, whereas they decline slower when there is a decrease in the crude oil price.

The key point is that in the presence of asymmetric behavior in retail prices, the standard tests for cointegration are not appropriate and they must be customized to account for asymmetric behavior. As in Enders and Granger (1998), and Enders and Siklos (2001), the proper way to introduce asymmetric adjustment is to let the deviation from the long-run equilibrium behave as a Threshold Autoregressive (TAR) process. Thus, it is possible to replace (2) with

$$\Delta\mu_t = I_t\rho_1\mu_{t-1} + (1 - I_t)\rho_2\mu_{t-1} + \epsilon_t \tag{3}$$

where I_t is the Heaviside indicator such that

$$I_t = \begin{cases} 1 & \text{if } \mu_{t-1} \geq \tau \\ 0 & \text{if } \mu_{t-1} < \tau \end{cases} \tag{4}$$

where τ is the value of the threshold. Since the exact nature of the non-linearity may not be known, it is also possible to allow the adjustment to depend on the change in μ_{t-1} (i.e., $\Delta\mu_{t-1}$) instead of the level of μ_{t-1}. In this case, the Heaviside indicator in equation (4) becomes:

$$I_t = \begin{cases} 1 & \text{if } \Delta\mu_{t-1} \geq \tau \\ 0 & \text{if } \Delta\mu_{t-1} < \tau \end{cases} \tag{5}$$

Enders and Granger (1998) and Enders and Siklos (2001) show that this specification is especially relevant when the adjustment is such that the series exhibits more "momentum" in one direction than the other; the resulting model is called momentum-threshold autoregressive (M-TAR) model[5]. *The F-statistics for the null hypothesis* $\rho_1 = \rho_2 = 0$ using the TAR specification of (4) and the M-TAR specification of (5) are called Φ_μ and Φ_μ^*. As there is generally no presumption as to whether to use (4) or (5), the recommendation is to select the adjustment mechanism by a model selection criterion such as the Akaike Information Criterion (AIC) or Schwarz's Bayesian Information Criterion (BIC).

Having different values of ρ_1 and ρ_2 implies asymmetric adjustment. A sufficient condition for stationarity of μ_t is: $-2 < (\rho_1, \rho_2) < 0$. Moreover, if the $\{\mu_t\}$ sequence is stationary, the least squares estimates of ρ_1 and ρ_2 have an asymptotic multivariate normal distribution; Tong (1983). If the null hypothesis $\rho_1 = \rho_2 = 0$ is rejected, it is possible to test for symmetric adjustment (i.e., $\rho_1 = \rho_2$) using a standard F-test. If the errors in equation (3) are serially correlated, it is possible to use a TAR or an M-TAR model augmented with lagged values of $\Delta\mu_t$ for the residuals. Thus, equation (3) is replaced by,

$$\Delta\mu_t = I_t\rho_1\mu_{t-1} + (1 - I_t)\rho_2\mu_{t-1} + \sum_{i=1}^{k} \gamma_i\Delta\mu_{t-i} + \epsilon_t \tag{6}$$

Lag length k can be determined by using model selection criteria such as AIC or BIC. The critical values to test the null hypothesis of cointegration depend on the number of variables as well as the number of lagged values in equation (6). Enders and Siklos (2001) report critical values using co-integrating vectors containing two

[5]Caner and Hansen (2001) present a statistical argument for M-TAR adjustment. If μ_{t-1} is a near unit root process, setting the Heaviside indicator using $\Delta\mu_{t-1}$ can perform better than the specification using a pure TAR adjustment.

variables.

This framework presumes the value of the threshold τ is known; however in practice one has to estimate the value of the threshold. As in Chan (1993) and Enders and Siklos (2001), we find a consistent value of the threshold by a grid search. First, we sort the $\{\mu_t\}$ sequence (or the in case of the M-TAR model, the $\{\Delta\mu_t\}$ sequence) in an ascending order. In order to have reasonable number of observations in each regime, we consider as a potential threshold, each μ_t between the lowest 15 percent and the highest 85 percent values of the series. We then estimate regressions in the form of (6) using each $\{\mu_t\}$ as a potential value of the threshold. The value resulting in the lowest residual sum of squares is a consistent estimate of the threshold.

3 Empirical Results

Table 2 presents cointegration test results on bilateral price relationships at different levels of the distribution chain in the form of (1), assuming threshold and momentum adjustment[6]. The table reports values of the adjustment coefficients ρ_1 and ρ_2, their t-values, and the Φ_μ and Φ^*_μ-statistics for the null hypothesis of a unit root in μ_t (no cointegration) against the alternative of cointegration with asymmetric adjustment. The lag length is selected such that the Bayesian Information Criterion (BIC) is minimized. The F-test for symmetric adjustment $\rho_1 = \rho_2$, the underlying long run relations, the consistent estimate of the threshold as well as the the value of BIC are also presented in the table.

The estimated Φ_μ and Φ^*_μ-statistics for the relationship between crude and spot

[6] All estimations are carried out using RATS software.

prices are 10.23 and 15.72. The critical values reported in Enders and Siklos (2001) at the 1 percent significance level with 250 observations and 1 lagged change are 9.18 and 8.84. As such, we reject the null hypothesis of a unit root in favor of cointegration with asymmetric adjustment between the crude oil price and retail gasoline prices. We also find similar evidence in the case of the relationships between crude oil prices and spot gasoline prices, the spot and wholesale gasoline prices, wholesale gasoline prices and retail gasoline prices. Even though there is evidence of cointegration with both TAR adjustment and M-TAR adjustment, clearly the BIC favors the M-TAR specification over that of TAR.

Notice that the F-statistics for the null hypothesis of symmetric adjustment ($\rho_1 = \rho_2$) reject symmetric adjustment for M-TAR specifications at conventional significance levels in all models. However, we fail to reject symmetry in all the TAR specifications. Here, we confirm the symmetry result by e.g., Bachmeier and Griffin (2003) based on the TAR specification, even though they assume a zero threshold. Since the BIC selects the M-TAR specification for all models, in what follows our discussion will focus on the M-TAR models.

The point estimates for ρ_1 and ρ_2 suggest substantially faster convergence for negative (below threshold) deviations from long run equilibrium than positive (above threshold) deviations except for the wholesale-retail gasoline price model. For example, in the crude oil price-retail gasoline price model, the point estimates of ρ_1 and ρ_2 suggest that negative deviations from the long run equilibrium resulting from decreases in retail gasoline prices or increases in crude oil prices (such that $\Delta\mu_{t-1} < -0.0151$) are eliminated at a rate of 7.4 percent per day while positive deviations are eliminated at only 1.6 percent per day. Of the four models considered, the largest discrepancy between the elimination of below and above-threshold deviations occurs at the transmission from the crude oil price to the spot gasoline price where negative deviations are eliminated at the rate 12.4 percent per day while positive deviations are eliminated at 1.6 percent per day. These results are mostly consistent with asymmetric adjustment in gasoline prices, and supportive of the so-called "rockets and feathers" story. However, the asymmetry here is not defined in terms of positive versus negative deviations from a long run equilibrium as in the "rockets and feathers" literature; rather it is defined in terms of the *rate of change* of the deviations from long run equilibrium that are below or above a certain threshold.

4 The Dynamic Adjustment of Gasoline Prices

It is known that coefficients of cointegration relations cannot be interpreted as elasticities[7] since the ceteris paribus assumption may not hold. The dynamic adjustment of downstream prices to upstream price shocks can be best understood by examining the impulse response functions. The evidence of cointegration with M-TAR adjustment also justifiers estimating the vector error correction representation.

Using the long run equilibrium between upstream and downstream prices, we estimate a Vector Error Correction Model (VECM) of the form:

$$\begin{aligned}\Delta x_t = A^+_{xx}(L)\Delta x^+_t + A^-_{xx}(L)\Delta x^-_t + A^+_{xy}(L)\Delta y^+_t + A^-_{xy}(L)\Delta y^-_t \\ - \alpha^+_1 I_t \hat{\mu}_{t-1} - \alpha^-_1 (1 - I_t)\hat{\mu}_{t-1} + e_{1t} \quad (7)\end{aligned}$$

[7]See, for example,Lutkepohl (1994).

$$\Delta y_t = A^+_{yx}(L)\Delta x^+_t + A^-_{yx}(L)\Delta x^-_t + A^+_{yy}(L)\Delta y^+_t + A^-_{yy}(L)\Delta y^-_t + \\ - \alpha^+_2 I_t \hat{\mu}_{t-1} - \alpha^-_2(1 - I_t)\hat{\mu}_{t-1} + e_{2t} \quad (8)$$

where $\hat{\mu}_{t-1}$ is obtained from the estimated long run equilibrium, the Heaviside indicator is set in accord with (5), $A_{ij}(L)$ are p-th order polynomials in the lag operator L, $\Delta x^+_t = max\{\Delta x_t, 0\}$, $\Delta x^-_t = min\{\Delta x_t, 0\}$; Δy^+_t and Δy^-_t are similarly defined.

Table 3 presents estimates of the error-correction parameters along with test statistics regarding weak exogeneity, and Granger causality. It is clear that the point estimates of α^+ and α^-, the error correction coefficients, are noticeably different in all models. While upstream prices in most models adjust in the "wrong" direction (have a positive sign), the downstream prices all adjust in the "right" direction by acting to eliminate deviations from long run equilibrium. The t-statistics for the error correction terms indicate that with the exception of crude oil price in the crude-spot model, all prices are weakly endogenous with respect to the long run equilibrium for at least one regime. Moreover, according to the point estimates of the error correction terms, with the exception of the spot-wholesale model, all downstream prices respond faster to below-threshold deviations from the long-run equilibrium than above-threshold deviations. For example in the crude-spot model, the spot gasoline price adjusts by about 1.5 percent of an above threshold deviation from the long-run equilibrium (such that $\Delta\mu_{t-1} \geq -0.0112$), but by 8.1 percent of a below threshold deviation. However, in the crude-retail, and the wholesale-retail models, these differences are less pronounced.

The estimated F-statistics for Granger causality in Table 3 indicate bi-directional Granger causality for all models at conventional significance levels except that the retail gasoline price fails to cause movements in the crude oil price. This justifies modelling upstream and downstream prices as a VECM rather than a univariate model. Indeed, as emphasized by Geweke (2004), it is possible for asymmetry in the markup relation to absorb as well as amplify asymmetries in upstream prices. By estimating a VECM, our model explicitly accounts for dynamic interactions between upstream and downstream prices.

Tests of symmetry based on the Vector Error Correction model in equations (7) and (8) are given in Table 4. The Table gives test statistics for all individual coefficient pairs in the positive and negative polynomials and the error correction terms as well as an overall joint symmetry test. The estimated F-statistics for coefficient pairs indicate that asymmetry is present at up to the sixth lag in the crude-retail and wholesale-retail models. However, the response of retail gasoline price to lagged changes in the wholesale price in the "wholesale to retail model" seems to be symmetric. Moreover, the error correction terms α^+ and α^- seem to be asymmetric except for the retail price adjustment in the "crude to retail model", the retail price adjustment in the "wholesale to retail model", and the crude price adjustment in the "crude to spot model". Finally, the test statistics reject the null hypothesis of joint symmetry in favor asymmetry at conventional significance levels for all variables in all models. Thus there is strong evidence the M-TAR specification entails asymmetric adjustment. The extent of asymmetry can be ascertained by examining the impulse response functions.

In order to investigate the dynamic response of retail prices to upstream price shocks, we present impulse response functions based on the VECM. We assume that the system is in long-run equilibrium and consider the impulse responses from typical one-standard deviation shock obtained using a Choleski decomposition. It is assumed that upstream price shocks are exogenous in that they affect downstream prices contemporaneously but that downstream price shocks affect upstream prices after one day.

As shown in Figure (1), a standard deviation shock (equal to 1.6 cents) to the crude oil price produces dramatically different responses in the retail gasoline price when the underlying shock is positive versus when it is negative. A positive crude oil price shock induces a gradual increase in the the retail gasoline price in about 15 business days where the retail price peaks at 1.9 cents. The retail price falls thereafter but the effect seems to be persistent. On the other hand, a negative shocks to the crude oil price elucidates a positive response after the initial impact effect even though the increase is not pronounced.

Figure 2 presents the effect of a unit standard deviation shock (equal to 1.6 cents) in the crude oil price on the spot gasoline price. Note that the asymmetry is not pronounced and the responses die down after two days. The effect of a standard deviation shock (equal to 2 cents) in the spot gasoline price on the wholesale price given in Figure 3 seems to produce asymmetric responses. Even though the response to the negative shock is not persistent, the effect of a positive shock seems to linger for awhile. Figure 4 depicts the responses of the retail gasoline price in the presence of one standard deviation wholesale price shocks (equal to 1.5 cents). While the positive shock produces positive responses that peak at 5 days, the negative shocks produce erratic responses that alternate between positive and negative changes with no persistence. Overall, the response of downstream prices to upstream price shocks is asymmetric. However, the the asymmetry is most pronounced in the latter part of the distribution chain, e.g., in the response of retail price to crude oil price shocks and in the response of the retail price to wholesale gasoline price shocks.

Insert Figures 1 - 4 here.

4.1 The size of the shocks

It is typical in the literature to consider the effect of a \$1 shock to an upstream price on the downstream price regardless of the historical size of the shocks[8]. Given the evidence that gasoline prices are cointegrated and behave as momentum *threshold* autoregressive processes, the size of the shocks matter. It is likely that market participants, particularly producers, judge crude oil price changes depending on their size. There is some evidence that large shocks in upstream prices produce less pronounced asymmetric effects in downstream prices. To contrast with a “typical” shock of a standard deviation in size, we present the response of upstream prices to a \$1 shock in downstream prices. The results are given in Figures 5-8.

Insert Figures 5 - 8 here.

Consider the effects on the retail gasoline price of a \$1 shock in crude oil prices (roughly 60 times the size of a typical shock in a day) given in Figure 5. It is evident that the effect of a “large” crude oil price shock produces less asymmetric responses in the retail gasoline price as compared to Figure 1. Notice also that the effects of a “large” crude oil price shock dissipate quickly as compared to a those of a “typical”

[8]See for example, Borenstein, Cameron, and Gilbert (1997), and Bachmeier and Griffin (2003).

shock. Nevertheless, the figure reveals that the response of the retail price to crude oil price shocks is still asymmetric. The response of the spot to crude, wholesale to spot, and retail to wholesale price shocks of a large size are given in Figures 6-8. These figures also reveal that the responses are mostly symmetric for large shocks at the initial and middle portion of the distribution chain. For example, the response of wholesale price to a large spot price shock appears symmetric in Figure 7 as compared to Figure 3.[9] The asymmetry that remains for large shocks appears to be at the retail stage.

Given that the asymmetry is most pronounced at the retail stage particularly for large shocks, the evidence points to some pricing discretion at the retail stage for small price changes. Consumer search costs can contribute to this temporary market power. As emphasized before, large shocks may justify costly searches by consumers and force gas stations to behave in a competitive way.[10] There may be other reasons why the size of the shocks is important. For example, drastic changes in crude supply as reflected in sizable changes in crude oil prices may make inventories irrelevant in buffering the effects of crude oil price on downstream prices. Moreover, a more sizable price change may be expected to be followed by other price changes in the same direction. These factors may justify passing crude oil costs to the downstream price regardless of whether the shock is positive or negative. However, when the size of a shock is small, the market may not expect the price to exhibit the same momentum if the price change is negative versus when it is positive.

[9]From a technical standpoint a large shock produces fewer crossovers between regimes.

[10]Indeed Borenstein and Shepard (1993) find evidence of price coordination at the retail level in the US.

Since there is asymmetry particularly at the retail stage for large shocks as well, one needs to look at alternative explanations of the asymmetry. As we emphasized before, market power, accounting practices, collusive behavior, inventories, and consumer response to changing prices can all play a role in the asymmetry. However our tests do not allow for distinguishing among these alternative sources of asymmetry.

5 Conclusions

This paper investigates crude, spot, wholesale and retail gasoline price adjustments in the U.S. for the period from December 1998 to January 2004 using a set of cointegration and error correction methods with non-linear adjustment. Tests confirm that each pair of prices are cointegrated. There is empirical evidence that adjustments toward long-run equilibria are asymmetric for all pairwise relationships. However, the asymmetry is not about positive versus negative deviations from an equilibrium as it is in the gasoline price literature; rather, it is about when the downstream prices exhibit more momentum in response to above threshold deviations from long run equilibrium than below threshold deviations. We provide consistent estimates of these thresholds and point to the importance of the size of the oil price shocks in determining the outcome of the ultimate gasoline price response. For large shocks, the responses of downstream prices to positive and negative upstream prices seem to be symmetric except at the retail level. For small shocks, the asymmetry is pronounced. This may be due to a limited local market power by retailers and consumer search costs.

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Table 1. Unit Root and Stationarity Tests

	cp_t	sp_t	wp_t	rp_t	Δcp_t	Δsp_t	Δwp_t	Δrp_t
				ADF Statistics				
	-2.83	-2.99	-4.17	-2.92	-27.15	-23.06	-15.60	-7.76
lags	1	1	3	5	1	1	1	4
				KPSS Statistics				
	3.63	2.64	1.79	3.20	0.08	0.05	0.04	0.16

Notes: Both ADF and KPSS tests include an intercept. The asymptotic critical value of the ADF test at the 5 percent level is -2.86; Fuller (1976, p. 373). The maximum lag for the ADF test is selected by the BIC. The lag truncation for the KPSS test is set at 10. The KPSS critical value at the 5 percent level is 0.46.

Table 2: Asymmetric Cointegration Test Statistics for Gasoline Prices

	Crude to retail		Crude to spot		Spot to wholesale		Wholesale to retail	
	TAR	M-TAR	TAR	M-TAR	TAR	M-TAR	TAR	M-TAR
ρ_1	-0.023 (-3.05)	-0.016 (-2.23)	-0.043 (-4.94)	-0.016 (-1.97)	-0.030 (-3.36)	-0.027 (-3.19)	0.012 (-2.33)	-0.032 (-4.64)
ρ_2	-0.043 (-3.36)	-0.074 (-5.15)	-0.032 (-2.24)	-0.124 (-7.78)	-0.055 (-3.99)	-0.085 (-4.83)	-0.018 (-3.95)	-0.010 (-2.47)
$\rho_1 = \rho_2 = 0$ (Φ_μ or Φ^*_μ)	10.23***	15.72***	14.62***	32.35***	13.50***	16.87***	10.42***	13.92***
$\rho_1 = \rho_2$ (F-Test)	1.65	12.50***	0.46	35.14***	2.30	8.91***	0.73	7.62***
Estimated threshold	-0.0895	-0.0151	-0.0674	-0.0112	-0.0962	-0.0236	-0.0747	0.0097
				Cointegrating relationship				
Constant	0.642		0.010		0.152		0.694	
Upstream price	1.209		1.217		1.077		0.720	
Number of lags	1	1	1	1	1	1	2	2
BIC	-673.98	-684.79	-1022.37	-1056.68	-204.08	-210.68	-1957.71	-1964.61

Notes: Lag length is determined by the BIC. The t-statistics are given in parenthesis. (*) indicates significance at 10%; (**) at 5 %; (***) at 1 %.

Table 3. Estimates of the Vector Error Correction Model

	Crude to retail		Crude to spot		Spot to wholesale		Wholesale to retail	
	Δcp	Δrp	Δcp	Δsp	Δsp	Δwp	Δwp	Δrp
α^{+} [a]	-0.006 (-0.83)	-0.011 (-4.29)	0.001 (0.17)	-0.015 (1.55)	-0.021 (-2.79)	-0.023 (-5.27)	0.033 (3.93)	-0.006 (-1.75)
α^{-} [a]	0.031 (2.55)	-0.016 (-3.36)	0.026 (1.73)	-0.081 (-4.36)	-0.006 (-0.38)	-0.011 (-1.14)	0.008 (1.57)	-0.007 (-3.06)
$A_{xx}(L)^{+} = A_{xx}(L)^{-} = 0$ [b]	2.15 (0.012)	--	6.51 (0.001)	--	7.92 (0.000)	--	58.76 (0.000)	--
$A_{xy}(L)^{+} = A_{xy}(L)^{-} = 0$ [b]	1.52 (0.108)	--	3.19 (0.041)	--	5.18 (0.005)	--	2.29 (0.007)	--
$A_{yx}(L)^{+} = A_{yx}(L)^{-} = 0$ [b]	--	4.81 (0.000)	--	4.68 (0.009)	--	225.55 (0.000)	--	5.63 (0.000)
$A_{yy}(L)^{+} = A_{yy}(L)^{-} = 0$ [b]	--	37.56 (0.000)	--	13.41 (0.000)	--	296.98 (0.000)	--	27.89 (0.000)
Number of lags [c]	6	6	1	1	1	1	6	6

Notes:
[a] The entries are estimated error correction terms given M-TAR adjustment with t-statistics in parentheses.
[b] The entries are estimated F-statistics that the parameters in the corresponding polynomials are zero with the p-values in parentheses.
[c] Lag length is selected by the multivariate version of the BIC.

Table 4. Tests of Symmetry in the Vector Error Correction Model

	Crude to retail		Wholesale to retail	
	Δcp	Δrp	Δwp	Δrp
a_{xx} (t-1)$^{+}$= a_{xx} (t-1)$^{-}$	5.29	105.11	9.10	76.41
	(0.022)	(0.000)	(0.003)	(0.000)
a_{xx} (t-2)$^{+}$= a_{xx} (t-2)$^{-}$	0.18	2.13	0.57	2.57
	(0.669)	(0.144)	(0.451)	(0.109)
a_{xx} (t-3)$^{+}$= a_{xx} (t-3)$^{-}$	0.12	3.38	1.39	5.98
	(0.725)	(0.066)	(0.238)	(0.015)
a_{xx} (t-4)$^{+}$= a_{xx} (t-4)$^{-}$	0.22	1.38	0.12	2.16
	(0.642)	(0.241)	(0.733)	(0.142)
a_{xx} (t-5)$^{+}$= a_{xx} (t-5)$^{-}$	8.08	6.87	0.29	5.11
	(0.005)	(0.009)	(0.589)	(0.024)
a_{xx} (t-6)$^{+}$= a_{xx} (t-6)$^{-}$	0.07	13.25	0.36	11.28
	(0.791)	(0.000)	(0.546)	(0.001)
a_{yx} (t-1)$^{+}$= a_{yx} (t-1)$^{-}$	1.52	0.08	2.51	0.39
	(0.218)	(0.783)	(0.113)	(0.535)
a_{yx} (t-2)$^{+}$= a_{yx} (t-2)$^{-}$	4.09	5.08	0.59	0.02
	(0.043)	(0.024)	(0.444)	(0.894)
a_{yx} (t-3)$^{+}$= a_{yx} (t-3)$^{-}$	3.69	1.10	0.43	0.05
	(0.056)	(0.295)	(0.511)	(0.820)
a_{yx} (t-4)$^{+}$= a_{yx} (t-4)$^{-}$	0.19	0.05	3.77	0.14
	(0.665)	(0.816)	(0.052)	(0.709)
a_{yx} (t-5)$^{+}$= a_{yx} (t-5)$^{-}$	0.22	3.07	0.68	0.05
	(0.638)	(0.080)	(0.409)	(0.831)
a_{yx} (t-6)$^{+}$= a_{yx} (t-6)$^{-}$	1.74	0.07	1.60	0.67
	(0.187)	(0.789)	(0.206)	(0.415)
$\alpha^{+} = \alpha^{-}$	8.13	0.79	6.73	0.03
	(0.004)	(0.375)	(0.01)	(0.862)
Joint Symmetry	2.77	11.07	2.65	8.09
	(0.001)	(0.000)	(0.009)	(0.000)
	Crude to spot		Spot to wholesale	
	Δcp	Δsp	Δsp	Δwp
a_{xx} (t-1)$^{+}$= a_{xx} (t-1)$^{-}$	8.30	0.86	3.88	8.08
	(0.004)	(0.353)	(0.049)	(0.005)
a_{yx} (t-1)$^{+}$= a_{yx} (t-1)$^{-}$	0.06	4.14	3.18	3.13
	(0.800)	(0.042)	(0.075)	(0.077)
$\alpha^{+} = \alpha^{-}$	2.17	10.02	3.30	27.34
	(0.141)	(0.002)	(0.070)	(0.000)
Joint Symmetry	4.12	5.99	3.45	11.86
	(0.006)	(0.000)	(0.016)	(0.000)

Notes: a_{xx} (t-j)$^{+}$= a_{xx} (t-j)$^{-}$ are estimated F-statistics that the coefficient pairs in the positive and negative polynomials are equal at the jth lag in the regression of variable x on itself. a_{yx} (t-j)$^{+}$= a_{yx} (t-j)$^{-}$ are estimated F-statistics that the coefficient pairs in the positive and negative polynomials are equal at the jth lag in the regression of variable y on variable x.. Joint symmetry gives the F- statistics that $A_{ij}(L)^{+}$ = $A_{ij}(L)^{-}$ and $\alpha^{+} = \alpha^{-}$. Numbers in parentheses are the associated p-values.

Figure 1. Response of retail gasoline price to a crude oil price shock

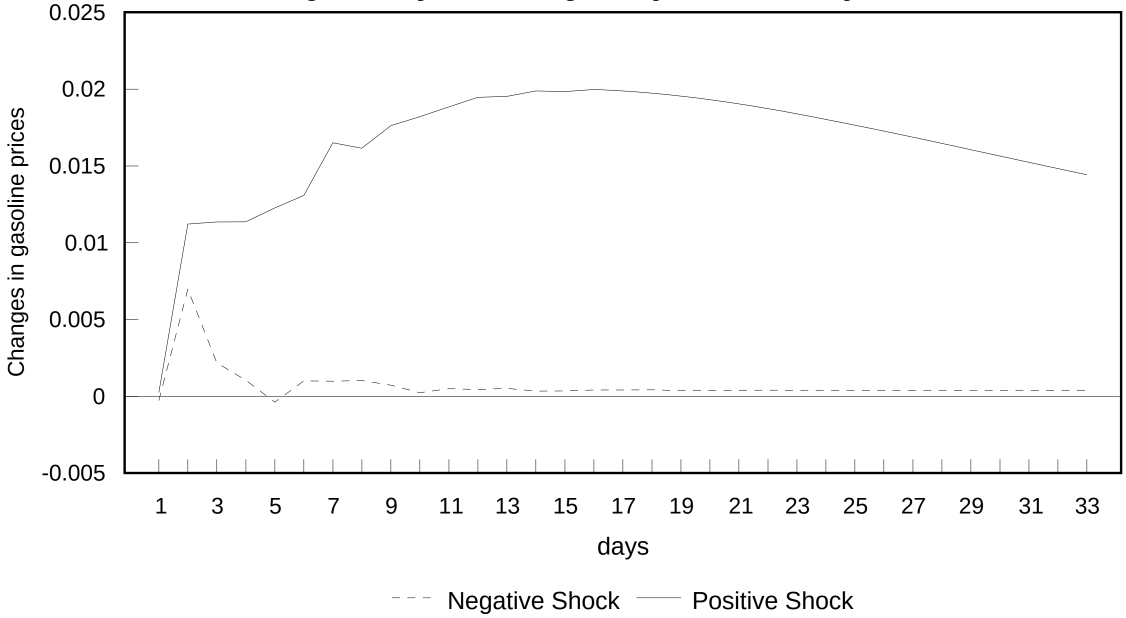

Figure 2: Response of the spot gasoline price to a crude oil price shock

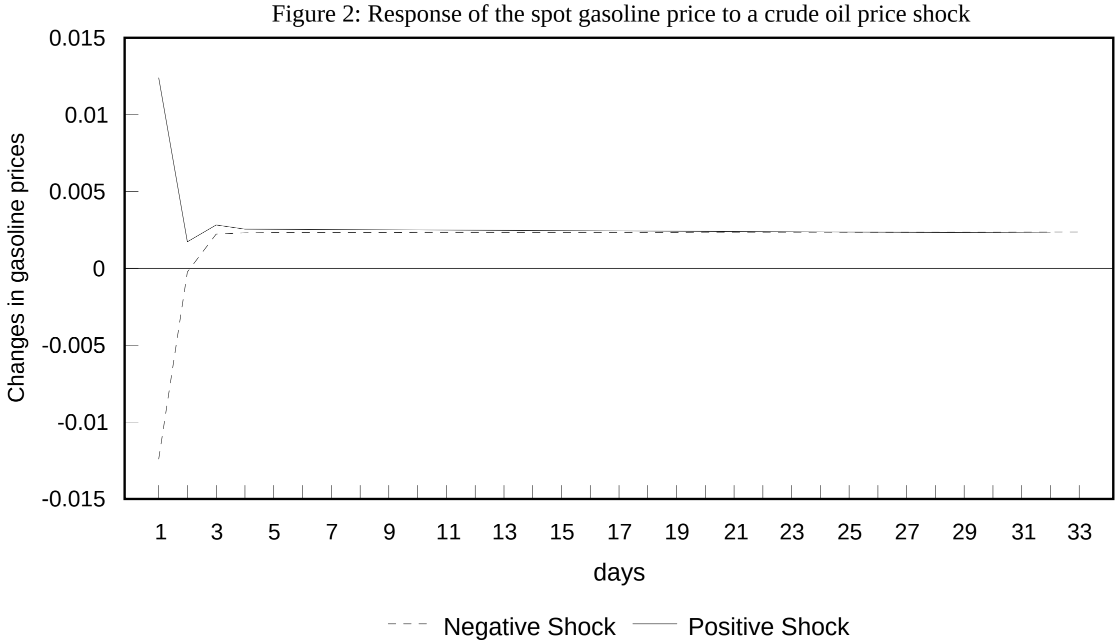

Figure 3: Response of the wholesale gasoline price to a spot gasoline price shock

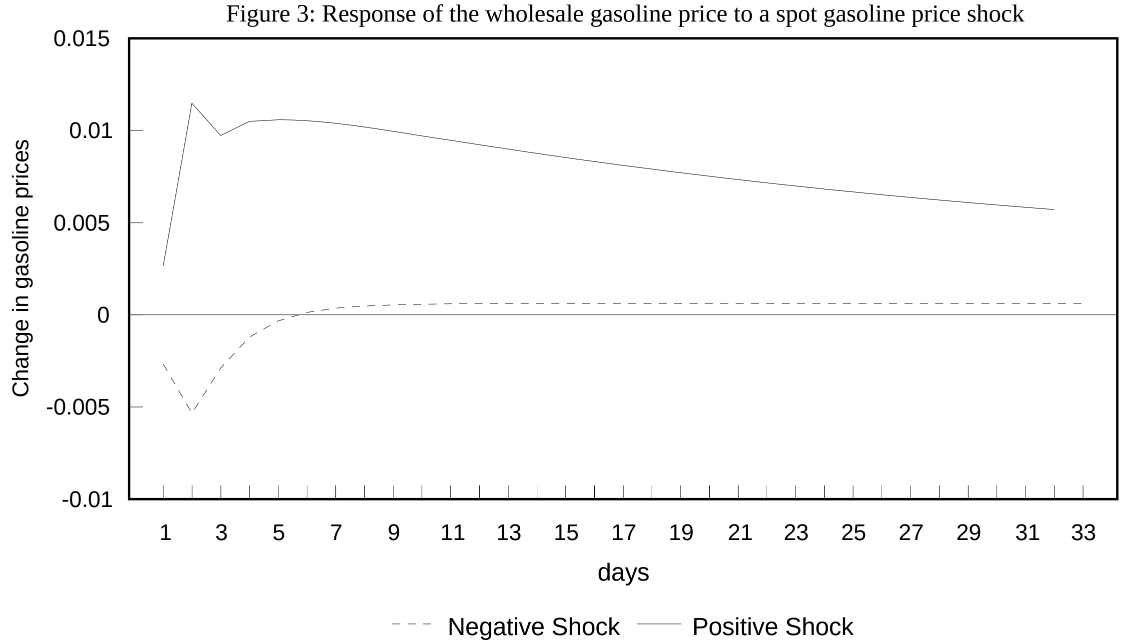

Figure 4: Response of retail gasoline price to a wholesale gasoline price shock

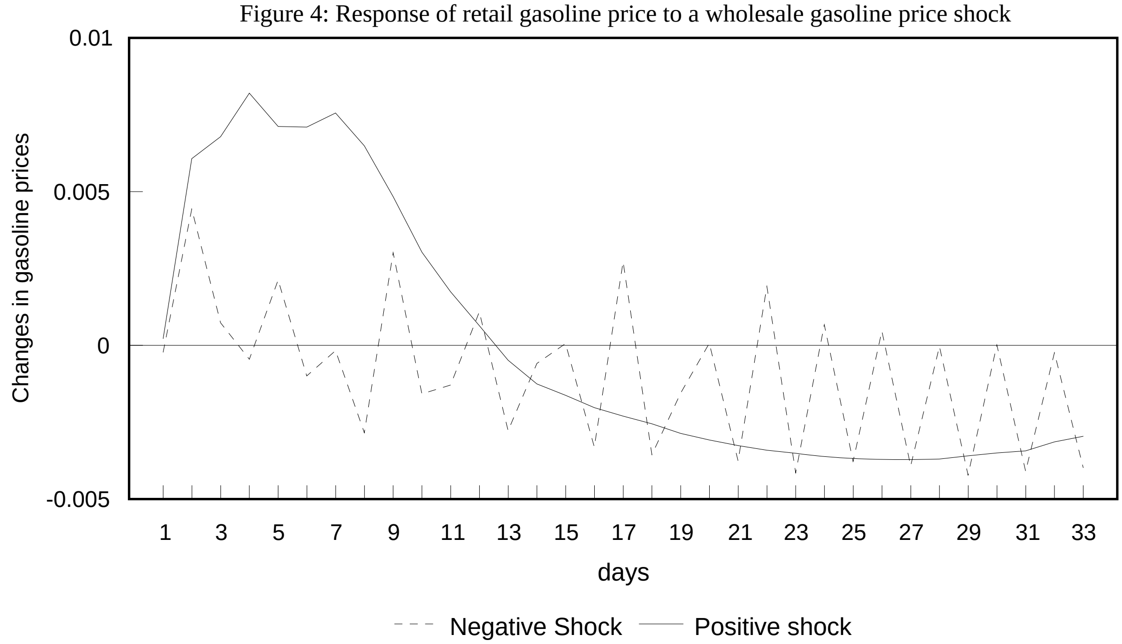

Figure 5. Response of retail gasoline price to a "large" crude oil price shock

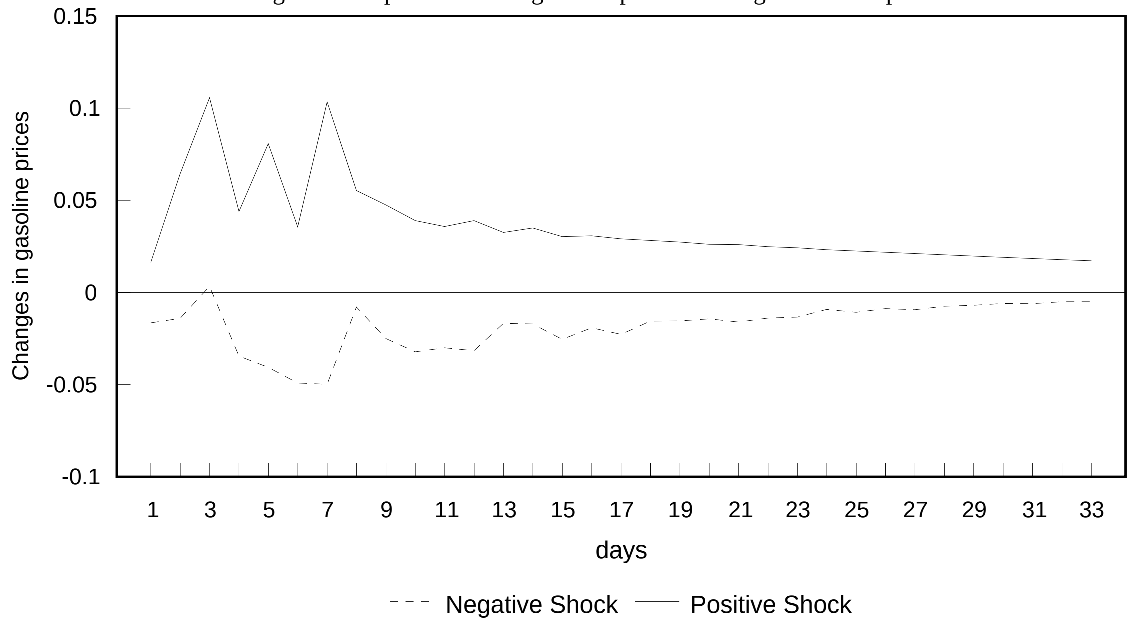

Figure 6: Response of the spot gasoline price to a "large" crude oil price shock

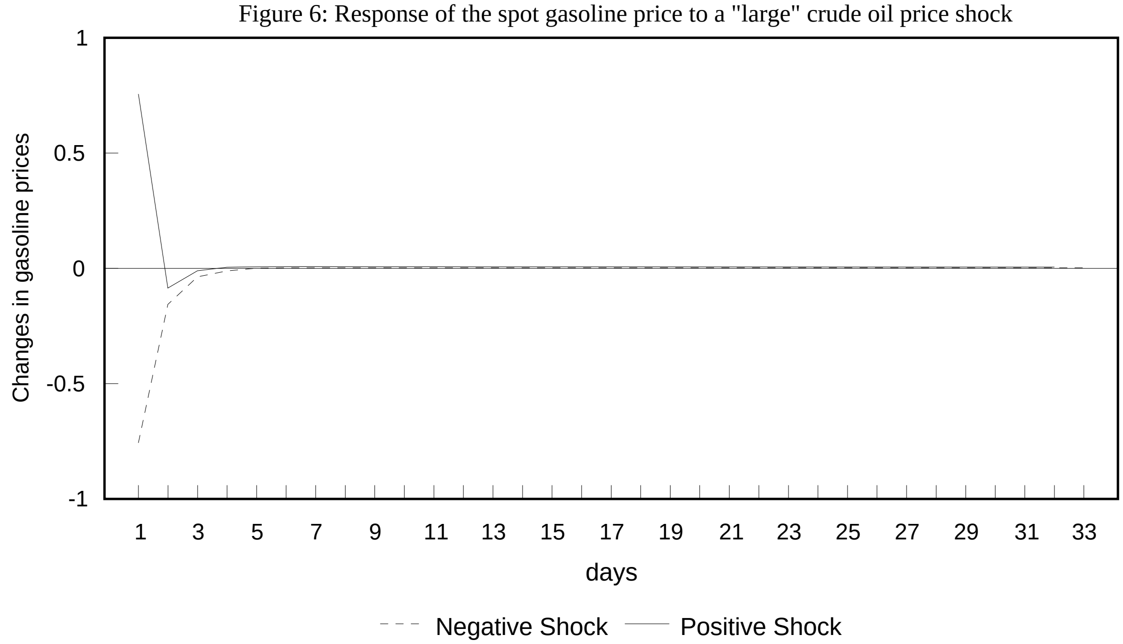

Figure 7: Response of the wholesale gasoline price to a "large" spot gasoline price shock

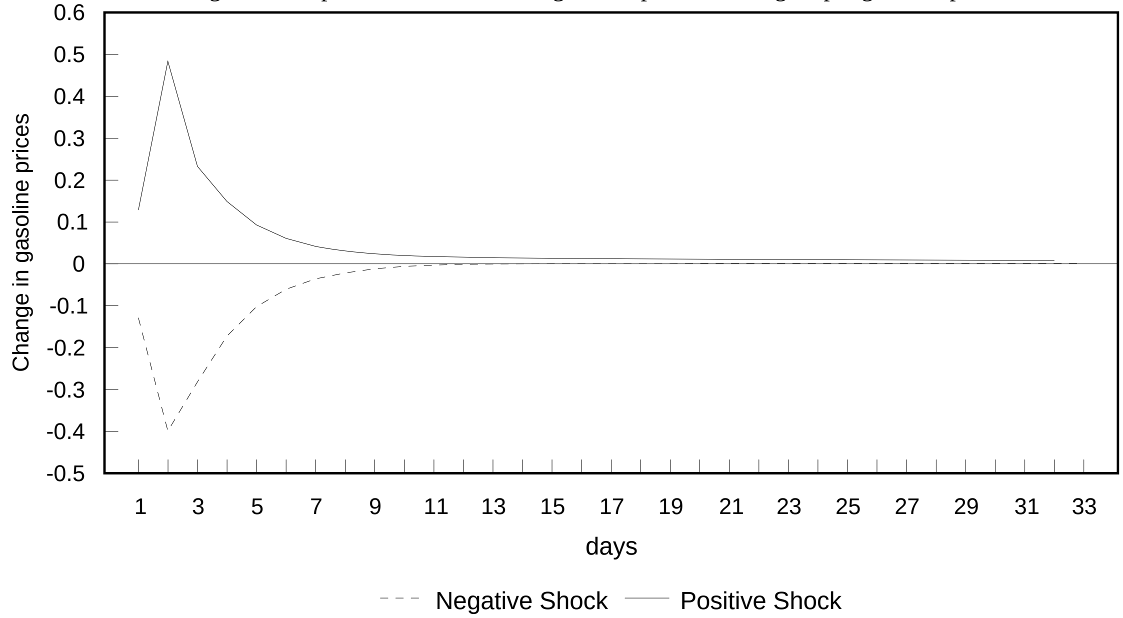

Figure 8: Response of retail gasoline price to a "large" wholesale gasoline price shock