Crude Oil and Gasoline Prices: An Asymmetric Relationship?

Nathan S. Balke
Research Associate
Federal Reserve Bank of Dallas
and
Associate Professor of Economics
Southern Methodist University

Stephen P. A. Brown
Senior Economist and Assistant Vice President
Federal Reserve Bank of Dallas

Mine K. Yücel
Senior Economist and Research Officer
Federal Reserve Bank of Dallas

Many claim to observe an asymmetric relationship between gasoline and oil prices…that gasoline prices respond more quickly when oil prices are rising than when oil prices are falling.

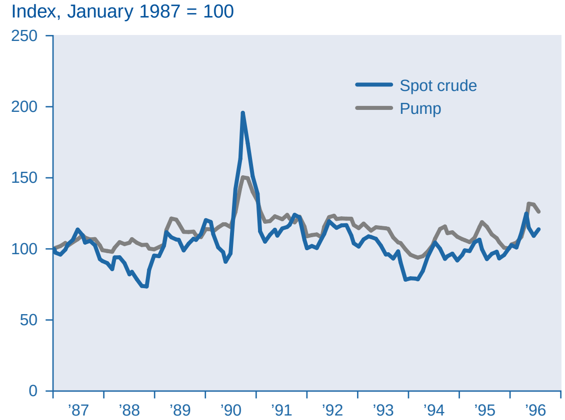
Gasoline accounts for about half the U.S. consumption of petroleum products, and its price is the most visible among these products. As such, changes in gasoline prices are always under public scrutiny. Many claim to observe an asymmetric relationship between gasoline and oil prices—specifically that gasoline prices respond more quickly when oil prices are rising than when oil prices are falling (*Figure 1*). President George Bush gave these concerns official weight during the Gulf War when he asked the oil companies to show restraint in raising prices for their products.

Much of the previous research provides econometric support for public claims of asymmetry in the movements of gasoline and crude oil prices. Bacon (1991) found asymmetry in the U.K. gasoline market, and Karrenbrock (1991), French (1991), Borenstein, Cameron, and Gilbert (1997), and a GAO report (1993) all found some evidence of an asymmetric response in U.S. gasoline markets. Norman and Shin (1991) found a symmetric response in U.S. gasoline markets.

Of these studies, one of the most comprehensive and compelling is that of Borenstein, Cameron, and Gilbert (1997), hereafter identified as BCG. They use a series of bivariate error-correction models to test for asymmetry in price movements in each of the various stages in the production and distribution of gasoline from the crude oil price through the refinery to the retail pump, using weekly and biweekly data from 1986 to 1992. They find strong and pervasive evidence of asymmetry.

As Shin (1992) has argued, however, the periodicity of the data, the sample period of estimation, and the model specification may have affected the results obtained in previous studies. To explore these issues, we extend the work of BCG by using several different model

Figure 1
Spot Crude Oil Prices and Retail Gasoline Prices



specifications with weekly data from 1987 through early 1996. We find that most of the price volatility originates upstream. We also find econometric evidence of asymmetry in the extended sample. The findings are sensitive to model specification but not to sample period.

Although popular opinion attributes asymmetry to market power, a number of competing explanations have been offered. This article presents an econometric exercise that attempts to identify whether asymmetry occurs; it does not address how asymmetry might arise. For an overview of the possible explanations, see the box entitled, "Why Does Asymmetry Arise?"

THE ORIGINATION AND TRANSMISSION OF PRICE SHOCKS

In theory, price shocks can originate at any point from crude oil prices to the final price at the gasoline pump. Shocks originating at an intermediate step, such as the wholesale price of gasoline, may reflect a bottleneck in distribution, while price shocks originating farther upstream are more likely to represent the effects of variation in crude oil supply. Price shocks originating at the retail level are more likely to represent variation in U.S. demand for gasoline. Given the history of oil-supply shocks and indications that demand for gasoline is relatively stable, intuition suggests that price shocks are more likely to originate upstream and be transmitted downstream.

To examine where price shocks originate and how they are transmitted across the U.S. market for gasoline, we use time-series methods. Specifically, we test for Granger causality and compute variance decompositions for each pair of upstream and downstream prices, including spot crude oil prices and spot, wholesale, and retail gasoline prices. As reported below, both the causality tests and variance decompositions generally confirm the intuition that price shocks more frequently begin upstream and are then transmitted downstream.

To motivate the relationship between a pair of upstream and downstream prices, consider a simple markup model,

$$(1) \qquad PD_t = a + bPU_t,$$

where PD_t is a downstream price, PU_t is an upstream price, and a and b are parameters indicating the relationship between the upstream and downstream prices.[1] The markup, a, represents the cost of refining, marketing, transportation, and/or distribution. The scalar, b, allows for differences in units and heat content but may also reflect other market phenomena.

The time-series analysis involves several steps. We check whether the prices are stationary. We then test for Granger causality, which allows an assessment of the lead–lag relationship between each pair of prices. Finally, we calculate the variance decompositions to assess the sources of shocks to the variables.

Data

To analyze the relationships between crude oil and gasoline prices, we use weekly data from January 1987 through August 1996. The oil price is the spot price for West Texas Intermediate crude, the spot price for gasoline is the New York Harbor Spot Price for unleaded regular, and the retail price is the self-service pump price for regular unleaded motor gasoline, with and without taxes. These series are obtained from the Weekly Energy Statistics of Haver Analytics. The wholesale price is from the Oil Price Information Service and represents an average wholesale price for unleaded gasoline across all U.S. wholesale distributors reporting data continuously from 1986 through August 1996.

Stationarity

As an initial step in our econometric work, we perform several diagnostic checks to assess the correct specification for the various series. We test for nonstationarity using augmented Dickey–Fuller and Phillips–Perron tests and conclude that we can reject the hypothesis that the series have a unit root. Because all our price series appear to be stationary, we represent the relationship between any pair of prices in log levels.

Causality

A causal relationship between two variables implies that changes in one variable lead changes in the other. To assess the lead–lag relationships for each pair of variables, we perform bidirectional Granger causality tests on each of the ten pairs of upstream and downstream prices as follows:

$$(2) \quad PD_t = \alpha_1 + \sum_{i=1}^{m} \beta_{1,i} PU_{t-i} + \sum_{i=1}^{m} \delta_{1,i} PD_{t-i} + \mu_{1,t} \text{ and}$$

$$(3) \quad PU_t = \alpha_2 + \sum_{i=1}^{n} \beta_{2,i} PD_{t-i} + \sum_{i=1}^{n} \delta_{2,i} PU_{t-i} + \mu_{2,t},$$

where PD_t is the downstream price; PU_t is the upstream price; α_1, $\beta_{1,i}$, $\delta_{1,i}$, α_2, $\beta_{2,i}$, and $\delta_{2,i}$ are parameters to be estimated; and $\mu_{1,t}$ and $\mu_{2,t}$ are white-noise residuals. The lag length used for estimation of each equation is the shortest lag length that yields white-noise residuals (as indicated by the Ljung–Box Q statistic with a probability of 10 percent).

Why Does Asymmetry Arise?

With a number of studies showing that gasoline prices respond more quickly when crude oil prices rise than when they fall, analysts have offered a number of explanations for the phenomenon.[1] Explanations include market power, search costs, consumer response to changing prices, inventory management, accounting practices, and refinery adjustment costs. For the banking industry, Neumark and Sharpe (1992) show that market concentration is an explanatory variable for the asymmetry found in interest rate movements. For the gasoline markets, however, no one has posited econometric tests that would allow the testing of the various explanations (including market power) for price asymmetry against the available data. Without such tests, it remains a matter of speculation whether the asymmetric response of gasoline prices to movements in crude oil prices is the result of market power or more benign forces.

Market Power and Search Costs

Market power is probably the greatest concern to those who observe that gasoline prices respond more quickly when crude oil prices rise than when they fall. Yet no formal model shows a relationship between market structure and asymmetric response of downstream prices to changes in upstream prices.[2] Were such a model to exist, it might involve firms that are concerned with maintaining a tacit collusion and/or consumer search costs.

Consider an industry with a few dominant firms that are engaged in an unspoken collusion to maintain higher profit margins. Reputation can be important to maintaining such a tacit agreement (Tirole 1990). If the firms value the tacit agreement and have imperfect knowledge of the upstream prices its competitors are paying, then each firm would face an asymmetric loss function in which it would be more reluctant to lower its selling price than to raise it. When upstream prices rise, each firm is quick to raise its selling prices because it wants to signal its competitors that it is adhering to the tacit agreement by not cutting its margin. When the upstream price falls, each firm is slow to lower its selling price because, in doing so, it runs the risk of sending a signal to its competitors that it is cutting its margin and no longer adhering to the tacit agreement. In the gasoline markets, such an explanation could be applied to each upstream price and its adjacent downstream price.

In the retail gasoline market, consumer search costs could lead to temporary market power for gas stations and an asymmetric response to changes in the wholesale price of gasoline. (See BCG, Norman and Shin 1991, Borenstein 1991, and Deltas 1997.) Each gas station has a locational monopoly that is limited only by consumer search. After consumers have searched, the profit margins at each gas station are pushed down to a roughly competitive level. When wholesale prices rise, each station acts to maintain its profit margins and quickly passes the increase on to customers. When wholesale prices fall, however, each station temporarily boosts its profit margins by slowly passing the decrease on to customers. Only after the customers engage in a costly and time-consuming search to find the lowest prices are the stations forced to lower prices to a competitive level.

More Benign Explanations

Although the existence of asymmetry could be consistent with market power, it is not the only explanation that economists have offered for the asymmetric response of gasoline prices to movements in crude oil prices. Alternative explanations include consumer response to changing prices, inventory management, accounting practices, and refinery adjustment costs.

An asymmetric consumer response to changing gasoline prices may contribute to the asymmetry between movements in crude oil and gasoline prices. If consumers accelerate their gasoline purchases to beat further increases when its price is rising, they will increase inventories held in automobiles and quicken the pace at which the price rises. If consumers fear running out of gasoline and do not slow their purchases of it when its price is falling by as much as they accelerated their purchases when prices rose, then the price of gasoline will fall more slowly than it rose.

Similarly, firms in the oil industry may view the short-run costs of unexpected changes in their inventories as asymmetric. (See BCG.) If the costs of operations rise sharply when inventories are reduced below normal operating levels, a reduction of upstream supply could lead a firm to raise its output prices aggressively to prevent a loss of inventories. If an increase in inventories above normal operating levels has a relatively small effect on costs, the firm could be less aggressive in reducing its selling prices when it experiences an increase in upstream supply. Hence, inventories would buffer downstream price movements less when prices are rising than when they are falling.

The asymmetry arising from changes in inventories could be enhanced by FIFO (first in, first out) accounting. If inventories fall when upstream supply is reduced, the firm will sell the products incorporating the higher upstream price sooner. If inventories rise when upstream supply is increased, the firm will sell the products incorporating the lower upstream price later.

Refiners also face high adjustment costs to changing their output, and, when possible, they slowly adjust output. When crude oil supplies are reduced and inventory reductions are costly, however, refiners as a group have little choice but to reduce output quickly, which would lead to fairly quick increases in gasoline prices. When crude oil supplies are increased, however, refiners slowly increase output, delaying the decreases in gasoline prices.

Notes

[1] Pricing asymmetries have been observed in a number of industries, including banking (Neumark and Sharpe 1992) and agriculture (Mohanty, Peterson, Wesley, and Kruse 1995).

[2] Variations of the kinked-demand model of oligopoly do not suggest an asymmetrical movement in the output price of an industry in response to common shocks to the input prices of the firms in that industry. See Scherer (1980) and Neumark and Sharpe (1992).

Causality runs from the upstream price to the downstream price if the coefficients $\beta_{1,i}$ are jointly significantly different from zero. Similarly, causality runs from the downstream price to the upstream price if the coefficients $\beta_{2,i}$ are jointly significantly different from zero.

In most cases, upstream prices seem to contain market information that is later incorporated in the downstream prices. As Table 1 shows, we find that causality runs from the upstream price to the downstream price for each pair, with two exceptions. The spot price for crude oil does not appear to lead the spot price for gasoline, nor does the retail price of gasoline without taxes seem to lead the retail price of gasoline including taxes. We do find, however, that the spot price for gasoline leads the spot price for crude oil, and the retail price including taxes leads the retail price excluding taxes. These findings suggest the possibility that for these two pairs of prices, information is incorporated in the downstream price a bit more quickly than in the upstream price. We also find that each of the gasoline prices Granger-cause the spot price for crude oil, which suggests that each of these prices contains market information that is later incorporated into the spot price for crude oil.[2]

Table 1
Significance of Granger Causality Tests
(Variable at left is the dependent variable)

	Oil	Spot gasoline	Wholesale	Retail without tax	Retail with tax
Oil	—	.014	.015	.024	.049
Spot gasoline	.53	—	.176	.097	.229
Wholesale	.002	.0	—	.455	.088
Retail without tax	.0	.0	.0	—	.0
Retail with tax	.0	.0	.0	.0	—

Table 2
Decomposition of Variance
(Percentage of forecast error variance of dependent variable explained by shocks to independent variable)

	Oil	Spot gasoline	Wholesale	Retail without tax	Retail with tax
Oil	—	18.1	2.7	4.4	.21
Spot gasoline	48.9	—	1.8	.47	.65
Wholesale	63.5	85.8	—	.15	.53
Retail without tax	63.3	84.7	87.2	—	.47
Retail with tax	45.8	42.8	83.7	91.5	—

NOTE: The variance decompositions are from bivariate VARs. The variable at left is the dependent variable. The pair orderings are from upstream to downstream.

Long-Run Sources of Variance

To find out which price shocks have been sources of volatility during the sample period, we construct a bivariate vector autoregressive (VAR) model to represent each relationship and calculate the variance decomposition for each pair of prices.[3] For given time horizons, the variance decomposition apportions the stochastic variability in a given price to shocks originating in itself and to shocks originating in the price with which it is paired. We consider a 30-week time horizon, which should represent the long run because the variance decomposition shows a minimal change after 30 weeks.

As Table 2 shows, the variance decompositions generally suggest that over the long run, price shocks originate in upstream prices and are transmitted downstream. In addition, the variance decompositions suggest that proximity enhances the importance of the upstream price as a source of variation in a downstream price. The one exception is in the relationship between the spot price for crude oil and the spot price for gasoline. In its pairing with the spot price of gasoline, the spot price for crude oil accounts for about one-half of the variance in the gasoline price over the long run. In its more distant pairing with the wholesale price of gasoline, the spot price of crude oil accounts for about two-thirds of the variance in the gasoline price over the long run.

A BASIC MODEL OF ASYMMETRY

Given the findings that price volatility most often originates in the upstream price of any price pair and that causality is stronger going from upstream prices to downstream prices, we restrict our inquiry to those cases in which the downstream price is the dependent variable and the upstream price is the independent variable, as is suggested by Equation 1. The relationships between upstream and downstream prices, coupled with the finding that each of the variables is stationary, suggest modeling asymmetry in levels as follows:

$$(4)\quad PD_t = \alpha + \sum_{i=0}^{n} \beta_i PU_{t-i} + \sum_{i=1}^{n} \gamma_i PD_{t-i} + \sum_{i=0}^{n} \delta_i U_{t-i} PU_{t-i} + \sum_{i=1}^{n} \lambda_i D_{t-i} PD_{t-i} + \mu_t,$$

where U_{t-i} is a variable that takes a value of one when PU_{t-i} is greater than PU_{t-i-1} and is zero otherwise; D_{t-i} is a variable that takes a value of one when PD_{t-i} is greater than PD_{t-i-1} and is zero otherwise; α, β_i, γ_i, δ_i, and λ_i, are parameters to be estimated; and μ_t is a white-noise

Table 3
Significance of Asymmetry Tests for Levels Model
(Variable at left is the dependent variable)

	Asymmetry type	Oil	Spot gasoline	Wholesale	Retail without tax
Spot gasoline	Indep. Var.	.075	—	—	—
	Total	.109	—	—	—
Wholesale	Indep. Var.	.239	.011	—	—
	Total	.097	.0	—	—
Retail without tax	Indep. Var.	.0	.42	.08	—
	Total	.0	.24	.013	—
Retail with tax	Indep. Var.	.0	.89	.35	.15
	Total	.0	.048	.067	.28

residual.[4] To facilitate comparison with BCG and to control for seasonal and time-varying pricing patterns, we include 51 weekly dummies and a time-trend variable in each regression.[5] The lag length used for estimation is the shortest lag length that yields white-noise residuals.

The regression's specification allows for asymmetry in the response of the downstream price to arise either from its own history or from the upstream price. Asymmetry is indicated if the coefficients δ_i and λ_i are jointly significantly different from zero.

Table 3 indicates that symmetry is rejected in half the price pairs at the 5 percent significance level, but the results are not very systematic. For instance, the tests indicate that retail prices for gasoline, both with and without taxes, respond asymmetrically to crude oil prices, while the retail price with taxes responds asymmetrically to the spot price for gasoline, but the retail price without taxes does not. In contrast, the retail price of gasoline without taxes responds asymmetrically to the wholesale price, but the retail price with taxes does not. In two of the pairings—spot gasoline with retail including taxes and wholesale with retail without taxes—the asymmetry seems to arise from the dependent variable's own dynamics. The lack of consistent results makes it difficult to determine in which stages of the market asymmetry arises. In addition, dynamic simulations indicate that for those cases in which asymmetry is statistically significant, it is relatively small.

These findings contrast with those of BCG, who find pervasive evidence of asymmetry that is large in magnitude, using data from 1986 to 1992. We use a shorter sample, 1987–92, and find it has no effect on the results.

AN ALTERNATE SPECIFICATION

Because the sample period used for estimation does not seem to explain the difference between the results above and those of BCG, we consider the differences between the specification of Equation 4 and that used by BCG. A model similar in specification to that used by BCG yields substantially different results from the levels model.

Having found that the shorter data series they utilized are difference stationary, BCG uses an error-correction model similar to Equation 4 for estimation. Allowing for asymmetry, including in the error-correction process, one representation of the error-correction model is

$$(5)\quad \Delta PD_t = a + \sum_{i=0}^{n} b_i \Delta PU_{t-i} + \sum_{i=1}^{n} c_i \Delta PD_{t-i} + \sum_{i=0}^{n-1} d_i U_{t-i} \Delta PU_{t-i} + \sum_{i=1}^{n-1} f_i D_{t-i} \Delta PD_{t-i} + y\,(PU_{t-1} - zPD_{t-1}) + \mu_t,$$

where ΔPD_t is the first difference of PD_t, the downstream price; ΔPU_t is the first difference of PU_t, the upstream price; a, b_i, c_i, d_i, f_i, and y are parameters to be estimated; z is the estimated parameter from the long-run relationship between PD_t and PU_t; and μ_t is a white-noise residual.

In estimation, however, BCG do not make use of the long-run restriction implied by the error-correction process, as the coefficients on the levels variables in their specification are left unrestricted, despite finding that their data series are difference stationary. Therefore, in the absence of asymmetry, their model would be equivalent to the levels model shown in Equation 4. Like BCG, we do not impose a long-run restriction in the estimation (which would not be supported by stationary data), but unlike BCG, we allow for asymmetry in the levels variables of the error-correction process, which allows us to rewrite Equation 5 as

$$(6)\quad PD_t = \alpha + \sum_{i=0}^{n} \beta_i PU_{t-i} + \sum_{i=1}^{n} \gamma_i PD_{t-i} + \sum_{i=0}^{n-1} \zeta_i U_{t-i} \Delta PU_{t-i} + \sum_{i=1}^{n-1} \eta_i D_{t-i} \Delta PD_{t-i} + \delta U_{t-1} PU_{t-1} + \lambda D_{t-1} PD_{t-1} + \mu_t,$$

where α, β_i, γ_i, ζ_i, η_i, δ, and λ are parameters to be estimated, and μ_t is a white-noise residual.[6] As with Equation 4, we include 51 weekly dummies and a time-trend variable in the regression. The lag length used for estimation is the shortest lag length that yields white-noise residuals. As is the case for Equation 4, the specification of Equation 6 allows for asymmetry in the response of the downstream price to arise either from its own history or from the upstream price. Asymmetry is indicated if the coefficients δ_i, λ_i, ζ, and η are jointly significantly different from zero.

Although Equation 6 differs from Equation 4 only in its specification of asymmetry, estimation with Equation 6 indicates more pervasive asymmetry.[7] As Table 4 shows, symmetry is rejected in nine of the ten price pairs. The error-correction specification barely rejects the hypothesis that the retail price of gasoline without taxes responds asymmetrically to the spot price of gasoline, but this is the only pairing in which asymmetry is not indicated. In two pairings—spot gasoline with wholesale and wholesale with retail without taxes—asymmetry seems to arise from the dependent variable's own dynamics. The pervasive asymmetry indicated by the error-correction model is consistent with the findings of BCG. Use of a shorter sample period, 1987–92, does not significantly affect the results.

The Magnitude of Asymmetry

To assess the extent of the asymmetry implied by the two models, we examine the response of the downstream price to both a permanent one-time increase in the upstream price and to a permanent one-time decrease in the upstream price. Figures 2 through 6 plot the differences between the downstream price's response to an increase and to a decrease in the upstream price.[8] The solid line in each figure represents the point estimate of the response, and the dashed lines represent a confidence band of two standard deviations.[9]

Figures 2 through 6 show that the asymmetry implied by the error-correction model is substantially different from that implied by the

Table 4
Significance of Asymmetry Tests for Error Correction Model
(Variable at left is the dependent variable)

	Asymmetry type	Oil	Spot gasoline	Wholesale	Retail without tax
Spot gasoline	Indep. Var.	.004	—	—	—
	Total	.004	—	—	—
Wholesale	Indep. Var.	.004	.08	—	—
	Total	.001	.0	—	—
Retail without tax	Indep. Var.	.0	.21	.06	—
	Total	.0	.08	.007	—
Retail with tax	Indep. Var.	.001	.035	.0	.0
	Total	.0	.0	.001	.0

Figure 2
Difference in Response of Spot Gasoline Price to Rising and Falling Price of Crude Oil

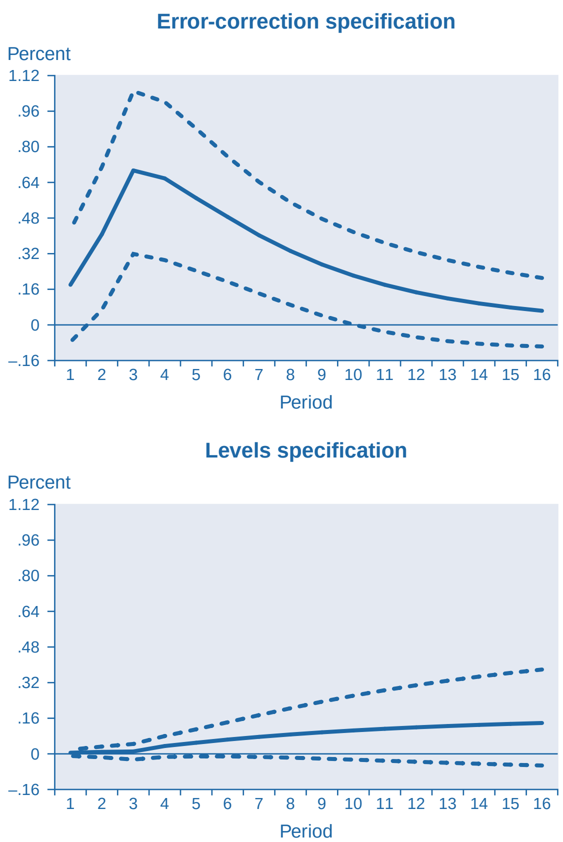


Figure 3
Difference in Response of Wholesale Gasoline Price to Rising and Falling Price of Crude Oil

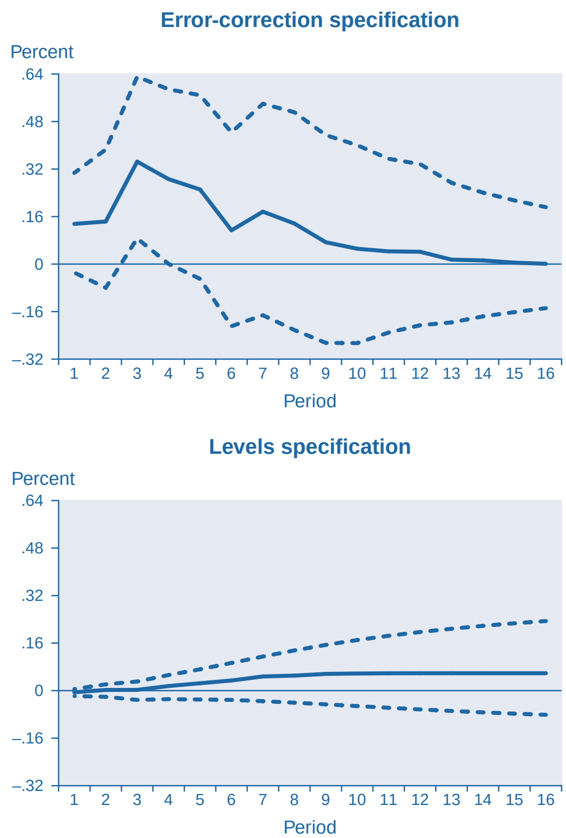


Figure 4
Difference in Response of Retail Price (With Tax) to Rising and Falling Price of Crude Oil

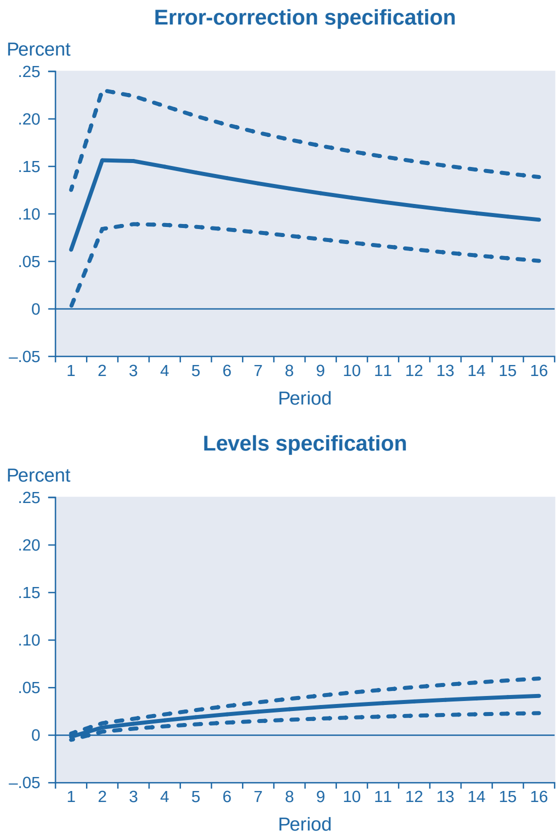
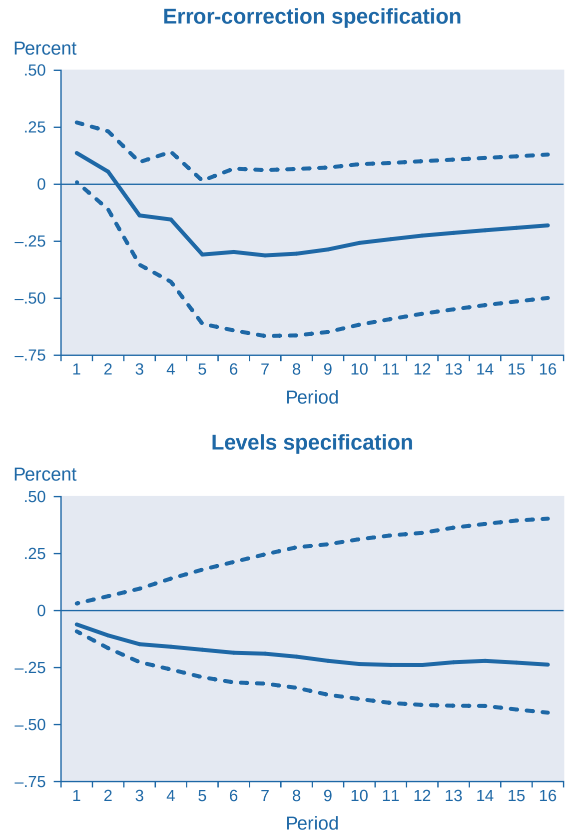


Figure 5
Difference in Response of Wholesale Gasoline Price to Rising and Falling Spot Price of Gasoline



levels model. For the error-correction model, the difference in the response of the downstream price to an increase versus a decrease in the upstream price is generally statistically significant. For the levels model, the difference is statistically significant only in a few cases. Furthermore, the magnitude of the asymmetry implied by the error-correction model is several times larger than that implied by the levels model, particularly during the first eight weeks following a change in the upstream price. Even for the price pairs in which the levels model does indicate significant asymmetry, the magnitude of the asymmetry is substantially smaller than that implied by the error-correction model (for example, see Figure 4).

For most of the error-correction models, the asymmetry peaks one or two weeks after the initial change in the upstream price and then slowly dies out. When retail (both with and without taxes) is the downstream price, the asymmetry can be fairly long-lived—longer than four months. In the few cases in which the levels model shows asymmetry, the asymmetry is quite persistent.

The one anomalous response is that of wholesale prices to changes in the spot gasoline price (*Figure 5*). In this case, both the error-correction model and the levels model imply that wholesale prices respond more to a decrease in the spot price than to an increase. The difference is not statistically significant in either model, however, in contrast to the F-tests reported in Tables 3 and 4.

DIFFERENCES IN SPECIFICATION

The fact that the two models yield such different results is puzzling. Under the null hypothesis of no asymmetry, the two models are identical (as the long-run restriction is not placed on the error-correction model). The differences arise solely in the specification of asymmetry.

To highlight the similarities and differences of the specifications represented by Equations 4 and 6, we create a generalized model in which the two specifications are nested. With some algebraic manipulation, the generalized model can be written as

$$PD_t = a + \sum_{i=0}^{n} b_i PU_{t-i} + \sum_{i=1}^{n} c_i PD_{t-i} + \sum_{i=0}^{n} d_i U_{t-i} PU_{t-i} + \sum_{i=1}^{n} f_i D_{t-i} PD_{t-i} + \sum_{i=0}^{n-1} g_i U_{t-i} PU_{t-i-1} + \sum_{i=1}^{n-1} h_i D_{t-i} PD_{t-i-1} + \mu_t, \tag{7}$$

where a, b_i, c_i, d_i, f_i, g_i, and h_i are parameters to be estimated, and μ_t is a white-noise residual. As with Equations 4 and 6, we also include 51 weekly dummies and a time-trend variable. The levels specification (*Equation 4*) is obtained if the coefficients g_i and h_i are zero. The error-correction specification is obtained if $g_i = -d_i$ and $h_i = -f_i$ for all i except $i = 1$, and $d_n = 0$ and $f_n = 0$.

Unfortunately, the differences between the models do not seem to lend themselves to sharply diverging economic interpretations. Consequently, we use Equation 7 to test for asymmetry and the restrictions imposed by the two models. Asymmetry is indicated if the coefficients d_i, f_i, g_i, and h_i are jointly significantly different from zero. The restriction representing the levels specification is rejected if the coefficients g_i and h_i are jointly significantly different from zero. The restriction representing the error-correction specification is rejected if $g_i = -d_i$ and $h_i = -f_i$ for all i except $i = 1$, and $d_n = 0$ and $f_n = 0$ are jointly significantly rejected.

Table 5 shows that for eight of the ten price pairs, the restrictions implied by the levels model are rejected, but the restrictions implied by the error-correction model cannot be rejected. For one pairing—spot gasoline with retail sans tax—the restriction implied by either model cannot be rejected. In the pairing of wholesale with retail sans tax, the restriction implied by the levels model cannot be rejected, but the restriction implied by the error-correction model is rejected.

For each of the nine pairings in which one specification seems to be preferred over the other, the preferred model indicates asymmetry. For the one pairing in which neither set of restrictions can be rejected, neither model indicates asymmetry. As shown by Table 6, asymmetry tests conducted with the general model are substantially consistent with the results from the preferred model for each pairing.

Figure 6
Difference in Response of Retail Price (with Tax) to Rising and Falling Wholesale Price

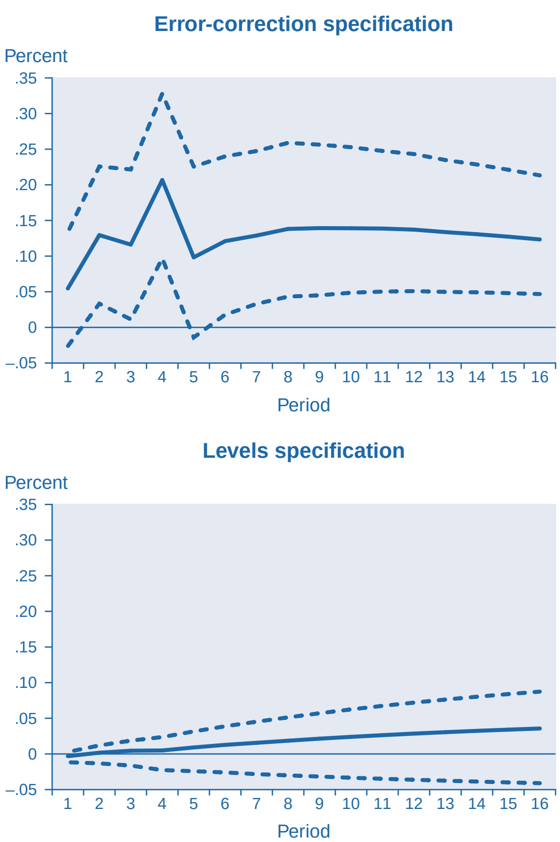


Table 5
Significance of Nesting Tests for Levels and Error-Correction Models
(Variable at left is the dependent variable)

	Asymmetry type	Oil	Spot gasoline	Wholesale	Retail without tax
Spot gasoline	LM	.01	—	—	—
	ECM	.06	—	—	—
Wholesale	LM	.006	.002	—	—
	ECM	.277	.132	—	—
Retail without tax	LM	.002	.242	.052	—
	ECM	.28	.592	.011	—
Retail with tax	LM	.0	.020	.014	.0
	ECM	.392	.301	.457	.143

Table 6
Significance of Asymmetry Tests for General Model
(Variable at left is the dependent variable)

	Asymmetry type	Oil	Spot gasoline	Wholesale	Retail without tax
Spot gasoline	Indep. Var.	.077	—	—	—
	Total	.009	—	—	—
Wholesale	Indep. Var.	.014	.013	—	—
	Total	.004	.0	—	—
Retail without tax	Indep. Var.	.001	.193	.034	—
	Total	.0	.18	.002	—
Retail with tax	Indep. Var.	.002	.061	.022	.0
	Total	.0	.002	.006	.0

Asymmetry Reconsidered

We have considered two model specifications to test for asymmetry in the response of gasoline prices to crude oil prices. Even though the two models differ only in their specification of asymmetry and are otherwise identical, they yield dramatically different results. A levels specification indicates that asymmetry is only found in a few cases and is small. An error-correction specification (without a long-run restriction) indicates that asymmetry is pervasive and large.

Unfortunately, the differences in specification do not seem to lend themselves to economic interpretation, which leaves us with a statistical criterion with which to evaluate the divergent findings. In most cases, tests with a more general model indicate that the error-correction model seems to fit the data better than the levels model, which suggests that the apparent asymmetry is one that operates on the rate of change in prices. If we accept the error-correction specification and conclude that asymmetry is pervasive and large, however, we must be concerned that the findings are sensitive to model specification.

NOTES

While retaining responsibility for any errors or omissions in the analysis, the authors thank Jim Dolmas, Fred Joutz, Evan Koenig, Jayeong Koo, Don Norman, and Marci Rossell for helpful comments on earlier drafts of the paper, and Carrie Kelleher and Dong Fu for able research assistance.

1 We conceptualize the relationship between upstream and downstream prices as a markup model but conduct our estimation in levels and natural logs. Although the results are substantially similar for both specifications, we report these results for natural logs because that specification is scale invariant.

2 Causality tests conducted with forms of the model that allowed for asymmetry yielded substantially similar results.

3 We use a Choleski decomposition that decomposes the residuals $\mu_{1,t}$ and $\mu_{2,t}$ into two sets of impulses that are orthogonal to each other. This permits the covariance between the residuals to be taken into account. The Choleski decomposition imposes a recursive structure on the system of residuals in which the ordering of the residuals associated with each dependent variable is specified. If the covariance between the residuals is sufficiently high, the ordering can affect the results. We found that changing the ordering had little effect on the results, except the pairing of spot crude oil with spot gasoline.

4 The inclusion of a contemporaneous upstream price term raises a concern about the possibility of simultaneous equation bias. The upstream origin of the shocks mitigates much of this concern, and BCG found that failure to instrument the variable has no appreciable effect on the results.

5 Statistical tests indicate that the seasonal dummies are significant in all regressions and the time-trend variable is significant in some regressions. Robustness checks indicate that the seasonal dummies and the time-trend variable have little effect on the results.

6 The presence of the dummies, U_{t-i} and D_{t-i}, prevents us from rewriting the asymmetric differenced terms as levels terms without placing restrictions on the resulting coefficients. See Equation 7 below.

7 The differences between Equations 4 and 6 are best seen in Equation 7 below.

8 Not all figures are presented here. The remaining figures are available from the authors.

9 Because the models are nonlinear, some care must be taken in computing these responses. For all the responses, we consider a one-unit change in the upstream price, given that the upstream price is initially equal to its sample mean. Because lagged values of the downstream price enter the model, downstream prices are set equal to the steady value implied by the model when the upstream price is equal to its sample mean. The confidence bands are calculated by Monte Carlo Integration. For each replication, we randomly draw the model parameters, $\tilde{\beta}$, from its posterior distribution, which is assumed to be $N(\hat{\beta}, V(\hat{\beta}))$, where $\hat{\beta}$ and $V(\hat{\beta})$ are the estimated parameters and their variance-covariance matrix, respectively. For a given realization of $\tilde{\beta}$, we then calculate the responses of the downstream price to an increase and a decrease in the upstream price. This is repeated 1,000 times to form the two-standard-deviation confidence band.

REFERENCES

Bacon, Robert W. (1991), "Rockets and Feathers: The Asymmetric Speed of Adjustment of U.K. Retail Gasoline Prices to Cost Changes," *Energy Economics* 13 (July): 211–18.

Borenstein, Severin (1991), "Selling Costs and Switching Costs: Explaining Retail Gasoline Margins," *Rand Journal of Economics* 22 (Autumn): 354–69.

Borenstein, Severin, A. Colin Cameron, and Richard Gilbert (1997), "Do Gasoline Prices Respond Asymmetrically to Crude Oil Prices?" *Quarterly Journal of Economics* 112 (February): 305–39.

Deltas, George (1997), "Retail Gasoline Price Response Asymmetries to Wholesale Price Shocks" (Paper presented at the Western Economic Association Meeting, Seattle, July 9–13).

French, Mark (1991), "Asymmetry in Gasoline Price

Changes” (Washington, D.C.: Board of Governors of the Federal Reserve System, August, Draft paper).

Karrenbrock, Jeffrey D. (1991), “The Behavior of Retail Gasoline Prices: Symmetric or Not?” Federal Reserve Bank of St. Louis *Review*, July/August, 19 – 29.

Mohanty, Samarendu, E. Peterson, F. Wesley, and Nancy Cottrell Kruse (1995), “Price Asymmetry in the International Wheat Market,” *Canadian Journal of Agricultural Economics* 43 (November): 355 – 66.

Neumark, David, and Steven A. Sharpe (1992), “Market Structure and the Nature of Price Rigidty: Evidence from the Market for Consumer Deposits,” *Quarterly Journal of Economics* 107 (May): 657– 80.

Norman, Donald A., and David Shin (1991), “Price Adjustment in Gasoline and Heating Oil Markets,” American Petroleum Institute Research Study no. 060 (Washington, D.C., August).

Scherer, F. M. (1980), *Industrial Market Structure and Economic Performance*, 2nd ed. (Chicago: Rand McNally).

Shin, David (1992), “Do Product Prices Respond Symmetrically to Changes in Crude Oil Prices,” American Petroleum Institute Research Study no. 068 (Washington, D.C., December).

Tirole, Jean (1990), *The Theory of Industrial Organization* (Cambridge, Mass.: MIT Press).

U.S. General Accounting Office (1993), “Energy Security and Policy: Analysis of the Pricing of Crude Oil and Petroleum Products,” GAO/RCED-91-17 (Washington, D.C.: Government Printing Office, March).