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Regional Comparisons, Spatial Aggregation, and Asymmetry of Price Pass-Through in U.S. Gasoline Markets

MICHAEL YE*, JOHN ZYREN**, JOANNE SHORE**, AND MICHAEL BURDETTE**

Abstract

Spot to retail price pass-through behavior of the U.S. gasoline market was investigated at the national and regional levels, using weekly wholesale and retail motor gasoline prices from January 2000 to the present. Asymmetric pass-through was found across all regions, with faster pass-through when prices are rising. Pass-through patterns, in terms of speed and time for completion, were found to vary from region to region. Spatial aggregation was investigated at the national level and the East Coast with the aggregated cumulative pass-through being greater than the volume-weighted regional pass-through when spot prices increase. These results are useful to the petroleum industry, consumers, and policy makers by providing a basis to estimate the retail price effects that result from a change in spot price. (JEL Q400, C50)

Introduction

In the petroleum industry, the majority of all products sold changes hands a number of times on its way from the point of production at a refinery to the point of ultimate consumption. Since each participant in this supply and marketing chain incurs some cost and wishes to make a profit, the price normally increases with each intermediate sale. As such, any change in price at the refinery, or at any intermediate point of sale downstream, would be expected to affect prices at each successive sale.[1] This is the so-called price pass-through in the economic literature.

In this paper, wholesale spot price to retail price pass-through in the gasoline market was investigated for several regions and subregions, as well as for the aggregate United States. Because all marketing channels culminate in retail sales competing side-by-side on the street, it is possible for many analytical purposes to focus on spot and retail prices only, with the difference between them representing the costs and profits of the distribution and marketing sector.

This subject is of interest to many audiences: the general public, the petroleum industry, and policy makers. The energy statistic most visible to American consumers is the retail price of gasoline. When substantial price changes occur, especially upward, there are often allegations of impropriety on the part of petroleum refiners and/or marketers. Traders and other industry participants would be interested since the relationships between spot and retail prices are consistent and predictable, to such an

*St. Mary's College of Maryland and **U.S. Department of Energy—U.S.A.

extent that changes in spot prices may be used to forecast subsequent changes in retail prices for the various regions. Issues related to price pass-through can be useful to policy makers, regulators, and administrators in evaluating market performance at the regional and national level.

The economic literature shows great interest in the pass-through phenomenon on many subjects, such as in international trade for the pass-through of exchange rates or tariffs to export and import prices [Parsely, 2001], in monetary policy for the pass-through of money supply to price inflation [Smets and Wouters, 2002], in fiscal policy for the pass-through of tax changes, in manufacturing for the pass-through of wages to output price [Peltzman, 2000], and for the product price pass-through of many agricultural commodities [Goodwin and Holt, 1999].

Gasoline price pass-through draws particular attention both in the empirical and theoretical literature [Duffy-Deno, 1996; Borenstein et al., 1997; Dale et al., 1999; Lewis, 2003; Sen, 2003; Zyren and Shore, 2003]. Economists are concerned whether price pass-through is symmetric or asymmetric. The asymmetry, if any, can be categorized into two types: amount asymmetry, in which the magnitude of changes at the wholesale and retail level are compared, and pattern asymmetry, which is concerned with different pass-through speeds for rising and falling prices. Much of the literature deals with the pattern asymmetry issue, testing its existence and explaining the factors causing any detected pattern asymmetry.

Spatial aggregation issues of price pass-through have been mentioned in the literature, but to our knowledge have not been thoroughly investigated, particularly in gasoline markets. While some cross-country comparisons of price pass-through behavior have been found in the literature [Galeotti et al., 2003], no intracountry regional comparisons have been found.[2]

The purpose of this work is to study U.S. national and regional wholesale to retail price pass-through in the gasoline market and to explore the possibility of pattern asymmetry and spatial aggregation effects. The focus is on the short-run pattern symmetries over five Petroleum Administration for Defense Districts and three subdistricts on the East Coast. Asymmetry was found in pass-through patterns for all regions, subregions, and at the U.S. national level. Pass-through patterns were found to be different from region to region in terms of speed and the number of weeks required for complete pass-through. Regarding spatial aggregation, the results show that for spot price increases, the aggregated cumulative pass-through is greater than the corresponding volume-weighted, composite, regional, and subregional pass-through.

In the next section, the data used in this paper are described. Pattern asymmetry, regional comparisons, and aggregation issues are analyzed in the following section, using asymmetric model specifications with error correction terms. Conclusions are drawn in the final section, together with several suggestions for future work. Supporting materials and results are organized in appendices at the end of the paper.

Data

Daily gasoline spot prices and weekly retail prices were collected from January 2000 to December 2003 for the five Petroleum Administration for Defense Districts (PADDs), the PADD 1 subdistricts, California, and U.S.;[3] all prices are in cents per gallon. The spot prices for various gasoline products at a number of major supply points, including the Gulf Coast, New York Harbor, Los Angeles, and others, were obtained from Reuters and DRI/PLATTS, Inc. Weekly retail gasoline prices are collected and published in "Motor Gasoline Price Survey" (Form EIA-878) by the Energy Information Administration.

The retail prices and weekly averages of the spot prices were defined to correspond to the same week. Since the retail data correspond to a Monday morning open-of-business price, the retail prices are modeled on spot prices in prior weeks. The appropriate terminal spot prices were matched to each regional average retail price produced by the "Motor Gasoline Price Survey."[4] The 10 retail prices used included all five PADDs, the three PADD 1 subdistricts, California, and the U.S. average. For each geographic area, the primary supply sources for the region were determined by examining the supply patterns, including flows from refineries, ports, and pipelines. This information was then matched with available spot price data, and where necessary, a weighted average spot price was created according to the portion of the region served by each spot market.

Weekly averages of the spot prices were calculated from the daily values.[5] Derivation of the weighting factors for the U.S., PADDs, and sub-PADDs were based on 2001 calendar year sales volumes reported in "Monthly Report of Prime Supplier Sales of Petroleum Products Sold for Local Consumption" (Form 782C), with intra-State splits, where necessary, based on the population of the regions served by the relevant spot market reported in Energy Information Administration [2001, Table 48].

The price series for all regions have significant seasonal components. However, the series were not deseasonalized because the spot and retail prices in the same region have nearly identical seasonal components.

Figure 1 shows the weekly average gasoline spot and retail prices in the United States. The figure shows that spot price movements are both faster and larger than retail price movements, and that the retail price response lags the spot price movement on the way up and on the way down, with the downward response appearing somewhat slower. This is a visual indication that pattern asymmetry may exist. Additionally, all evidence to date indicates that amount symmetry exists in all gasoline markets because retail prices have a close relationship with spot prices that does not change over time [Burdette and Zyren, 2003, Table 6; also Dale et al., 1999, Table 3.7].[6]

However, the asymmetry effects on gasoline price relative to other factors affecting price, such as changes in the international crude oil markets, appear to be small. As described by Burdette and Zyren [2003], a symmetric model was used to demonstrate that changes in spot gasoline prices are passed through to retail in an exponentially declining pattern over a period of about eight weeks. That work showed that such a

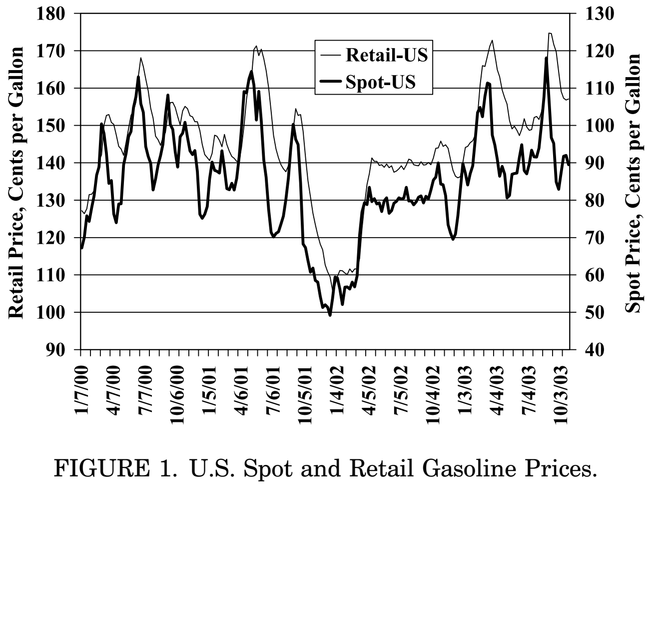

FIGURE 1. U.S. Spot and Retail Gasoline Prices.

symmetric lag pattern can produce a forecast that reasonably approximates observed retail gasoline patterns, suggesting that asymmetry, if any, is small in the context of overall retail price changes.

The manner in which prices are passed through the various levels of petroleum markets is not uniform across regions. The differences between regions in the speed of pass-through may be due to a number of factors related to both logistics and business practices. Although no formal studies exist to the authors' knowledge, it is assumed that the geographic distance between a retail market and the spot market used in the pass-through calculation is a factor of some significance [Zyren et al., 1997]. Additionally, it appears that there may be some correlation between the market shares of certain sales channels, such as rack vs. Dealer Tank Wagon sales, and the speed of pass-through. With these potential sources for regional differences, the price pass-through pattern is statistically tested in the next section to determine if it is asymmetric and if there are any regional differences in pass-through speed.

Results

The different patterns in behavior of the spot and retail prices observed in Figure 1 are due to two factors. The reason that retail prices have smaller fluctuations than spot prices is due to the partial adjustment of the retail price in a single period to spot price changes, and the broader width of the retail price peaks is due to lagged adjustment and pattern asymmetry. The latter proposition is examined in this paper. Statistical tests were performed to determine whether rising spot prices result in retail prices responding faster than falling spot prices. This section specifies the model used to estimate the retail price response and test for pattern asymmetry.

Based on the well-known existence of a unit root and a cointegrating relationship between spot and retail prices, both spot and retail prices are modeled in first differences, with an error correction term added to reflect the long-run relationship.[7] Furthermore, to capture potential asymmetric responses of retail price to changes in spot price, both short- and long-run relationships are broken into separate terms of positive and negative movements of spot price [Enders and Granger, 1998; and Abdulai, 2002]. The pass-through model used is:[8]

$$\Delta \mathrm{RETAIL}_t = \sum_{i-1}^{i=k^+} \beta_i^+ \Delta^+ \mathrm{SPOT}_{t-i} + \sum_{j=1}^{j=k^-} \beta_j^- \Delta^- \mathrm{SPOT}_{t-j} + \gamma^+ \mathrm{EC}_{t-1}^+ + \gamma^- \mathrm{EC}_{t-1}^- + \varepsilon_t \quad (1)$$

where:

Δ	is the first order backward difference operator;
Δ^+	refers to the case where spot price increases;
Δ^-	refers to the case where spot price decreases;
RETAIL_t	is the Monday morning gasoline retail price in week t;
SPOT_t	is the average gasoline spot price in week t;
EC^+	is the error correction term when retail price is above its long-term level;
EC^-	is the error correction term when retail price is below its long-term level;
k^+	is the number of lags for spot price increase;
k^-	is the number of lags for spot price decrease;
ε_t	is the error term at time t.

Lag length was chosen by using the values that minimized the Akaike Information Criterion. The coefficients β's and γ's in equation (1) were estimated using OLS for the period from April 2000 to present using weekly data. Details of the estimation results are tabulated in Appendix A. Pattern asymmetric responses are reflected in the β set and γ set of parameters. In other words, lack of pattern asymmetry in the pass-through of spot prices to retail is indicated if $\beta^+ = \beta^-$ for $i=j$, $\gamma^+ = \gamma^-$, and $k^+ = k^-$. Also, if $\beta^+ > \beta^-$ for $i = j$, particularly in the early lagged periods, then the price pass-through is faster when prices are rising than when they are falling. The speed of pass-through is indicated by β_1, which is the coefficient for the first lagged period.[9]

It is also important to note that the coefficients on the error correction terms provide an alternative and independent criterion for detecting pattern asymmetry in price pass-through estimations. The coefficients γ^+ and γ^-, which are both expected to be negative, capture the speed of adjustment towards the long-run equilibrium when price is above and below the long-run equilibrium. More specifically, $|\gamma^+| < |\gamma^-|$ indicates a slower immediate downward adjustment towards the long-run equilibrium when retail price is above equilibrium and faster immediate upward adjustment towards the long-run equilibrium when retail price is below equilibrium.[10]

In the subsequent discussion, it is important to realize the anomalous nature of the gasoline market in PADD 4 due to the lack of a viable spot market. PADD 4 is inherently different from the other four PADDs because gasoline production in this PADD is approximately equal to regional demand, and the PADD has "imports" of gasoline from Tulsa, OK, approximately equaling "exports" to the Pacific Northwest region of PADD 5. This results in retail price changes being affected by spot prices of Tulsa, OK, and PADD 5, rather than a more local market.

Major results are organized in Tables 1 and 2. Table 1 shows that the aggregate pass-through speed of PADD 1 is bracketed by its sub-PADDs; similarly, the speed for the U.S. is bracketed by its PADDs. The pass-through speed for spot price increases, as measured by the coefficient of the first lag of the spot price, ranges between 16 percent for PADD 4 and 74 percent for PADD 2, whereas the speed for price declines is much slower, ranging from 11 percent in California or PADD 5 to 46 percent in PADD 2. These results show evidence of pattern asymmetry because the pass-through speed, as measured by the coefficient of the first lag, is significantly greater when spot prices increase than when spot prices decrease in all regions (except for PADD 4), subregions, and the U.S. average.

TABLE 1
Pass-Through Speed and Pattern Asymmetry

Region	β_1^+	β_1^+ Std. Err.	β_1^-	β_1^- Std. Err.	$(\beta_1^+ - \beta_1^-)^a$
PADD 1	0.422	0.0267	0.144	0.0221	0.278
PADD 1A	0.215	0.0250	0.129	0.0209	0.085
PADD 1B	0.293	0.0252	0.114	0.0203	0.179
PADD 1C	0.487	0.0338	0.192	0.0312	0.295
PADD 2	0.740	0.0454	0.464	0.0383	0.276
PADD 3	0.488	0.0300	0.173	0.0278	0.315
PADD 4	0.158	0.0288	0.166	0.0293	−0.008
PADD 5	0.314	0.0274	0.110	0.0279	0.204
CA	0.355	0.0316	0.106	0.0340	0.250
U.S.	0.566	0.0325	0.285	0.0278	0.281

[a]All differences are significantly different from zero at the 99% confidence level, except PADD 1A, which is at 95%, and PADD 4, which is insignificant.

TABLE 2
Pattern Asymmetry Test Results

	Test 1			Test 2		
Region	No. of Lags[a]	F-stat.	Prob.	No. of Lags	F-stat.	Prob.
PADD 1	4:10	9.478	0.000	4	14.902	0.000
PADD 1A	4:12	2.408	0.007	4	3.355	0.011
PADD 1B	4:12	3.435	0.000	4	6.800	0.000
PADD 1C	9:11	5.339	0.000	9	5.703	0.000
PADD 2	4:5	5.711	0.000	4	6.293	0.000
PADD 3	9:11	7.052	0.000	9	7.483	0.000
PADD 4	8:12	2.165	0.016	8	1.785	0.083
PADD 5	11:9	4.043	0.000	9	4.271	0.000
CA	11:9	3.800	0.000	9	4.445	0.000
U.S.	3:11	10.360	0.000	3	15.090	0.000

[a]Number of positive lags: number of negative lags.

The difference between the positive and negative pass-through speeds is shown in the last column of the Table 1. This difference ranges from -0.01 to 0.32, insignificant to 32 percent in the first week, and seems to be related to nearness of all portions of the region to major spot market centers and to the petroleum product distribution infrastructure of the individual regions. The difference seems to be more closely related to the positive speed (correlation of 0.77 for the PADDs 1, 2, 3, 4, and 5) than to the negative speed (correlation of 0.25 for the five PADDs).

In order to test for pattern asymmetry, Wald tests were performed to determine if $\beta^+ \neq \beta^-$ in the same week. The null hypothesis of pattern symmetry is a joint test of $\beta_i^+ = \beta_i^-$, for i = week 1, week 2, etc., while the alternative hypothesis of pattern asymmetry is $\beta_i^+ \neq \beta_i^-$ for any i. The only difficulty comes with the use of different numbers of lags for price increases and price decreases. Two different tests were used to ensure valid conclusions. Test 1 is similar to that described by Bettendorf et al. [2003] where the coefficients of the missing lagged variables are set to zero.[11] However, this method biases the joint test toward accepting H_0 because most of the response from a spot price impulse will occur in the shorter lags. Thus, the appearance of an asymmetrical response would be more easily recognized with shorter lags. Even though many of longer negative lag coefficients are significantly different from zero, they simply indicate the slow adjustment of the retail price toward the equilibrium level. Since this test is a joint test, which sets the corresponding positive coefficients to zero,[12] many insignificant or marginally significant terms are included, thus making the test statistic biased toward zero, i.e., accepting H_0. This paper proposes a second test, Test 2, where only the first $k = \min(k^+, k^-)$ lag coefficients are jointly tested; this test should reduce the aforementioned bias. The test results are detailed in Table 2, which indicates pattern asymmetry for both tests in all cases.

Pattern asymmetry can also been seen from the long-term relationship, indicated by the error correction term. Results in Table 3 show that coefficients, except for PADD 4, are significant and of larger absolute magnitude when retail price is below the long-run level, indicating a faster response when prices are below long-run equilibrium, while coefficients, except for PADD 1A, are insignificant when retail price is above the long-run level, indicating a slower adjustment when prices are above equilibrium. These results

TABLE 3
Evidence of Asymmetric Pattern Pass-Through in Long Run

Region	$(\gamma^{+})^{a}$	$(\gamma^{-})^{a}$	$(\gamma^{+} - \gamma^{-})^{a}$
PADD 1	−0.031	−0.100***	0.070
PADD 1A	−0.123**	−0.212***	0.089**
PADD 1B	−0.068	−0.142***	0.075*
PADD 1C	−0.028	−0.121***	0.093*
PADD 2	−0.113	−0.152**	0.039
PADD 3	−0.041	−0.104***	0.063
PADD 4	−0.050	−0.042	−0.008
PADD 5	0.024	−0.126***	0.150***
CA	0.022	−0.146***	0.168***
U.S.	−0.006	−0.102***	0.096*

[a] *** indicates 99 percent, ** indicates 95 percent, and * indicates 90 percent significance levels, respectively.

are consistent with the pattern asymmetry test results in Table 2. As would be expected, the negative ECM coefficients for PADDs 1–5 are correlated with the speed of pass-though (positive speed correlation is −0.83, and negative speed correlation is −0.56) and also with the difference in pass-through speed (correlation is −0.77). Appendix B discusses the interrelationships between the estimated parameters.

Turning to the aggregation issues, the pass-through speeds in Table 1 suggest that the aggregate speed for PADD 1 is some combination of the speeds in PADDs 1A, 1B, and 1C, and that the speed for the aggregate U.S. is some combination of the speeds in the individual PADDs. To investigate if there is an aggregation problem, volume-weighted sales were used to adjust the coefficients of each component; the results are shown in Figures 2 and 3.

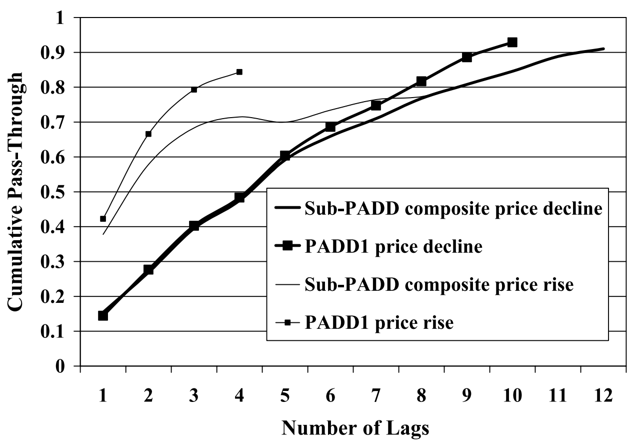

FIGURE 2. Pass-Through Comparison of Composite Sub-PADDs with PADD 1.

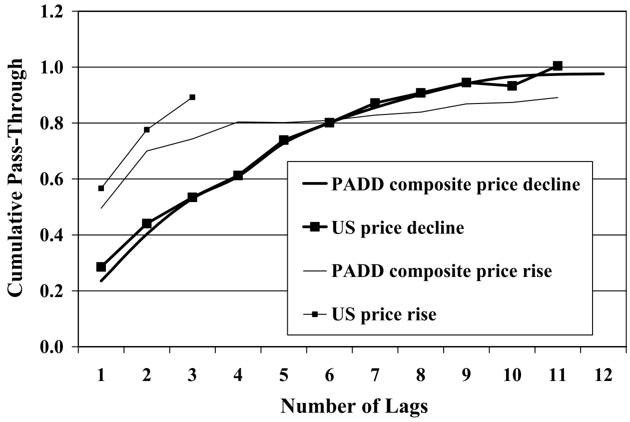

FIGURE 3. Pass-Through Comparison of Composite PADDs with U.S.

Both figures demonstrate that there is no aggregation problem when prices decline. However, when prices rise, the figures show that the weighted sub-PADD response is less than that for PADD 1 as a whole (see Figure 2), and that the weighted PADD response is smaller than the aggregate U.S. response (see Figure 3). This is due to the shorter adjustment period in the aggregate region (four periods for PADD 1 and three periods for U.S.) than in the individual subregions. In particular, in PADD 1, the total response is four periods long, while the responses for the individual sub-PADDs range from four to nine; for the U.S., the response is three periods long, while the individual PADDs range from four to 11 periods. This volume weighting of longer response needed for amount symmetry in the subregions results in a smaller and slower volume-weighted response than the faster aggregate response. However, this aggregation problem may be a statistical artifact because, generally, the standard errors for the positive coefficients in the aggregate regions, PADD 1 and U.S., are smaller than for the corresponding subregions. For the case when price decreases, this aggregation affect does not appear because the number of lags for the aggregate region and its subregions are similar. In summary, if pass-through aggregation issues exist, they will occur when the lag lengths are very different, i.e., when prices are rising.[13]

In summary, pattern asymmetry is present in all regions, with retail prices rising faster than they fall. The pass-through speed is similar for most regions, with only PADD 2 being significantly faster. Investigation of regional and subregional data shows no major differences in market behavior.

Conclusions and Suggestions for Further Work

Data series on weekly gasoline spot and retail prices from 2000 to the present were collected and generated, covering the U.S., five regions, and three subregions. A pass-through model was used to investigate potential price pass-through asymmetry, regional differences, and spatial aggregation issues. Spot to retail pass-through patterns were found to be asymmetric across all regions. Moreover, pass-through patterns are different from region to region in terms of speed and the number of weeks. Finally, when spot price goes up, the aggregated cumulative pass-through is faster than a volume-weighted regional and subregional pass-through.

Several implications for interpreting market behavior follow from these findings. The first is that, since asymmetry was found at all regional levels, national asymmetry is due to regional price behavior. Second, since a single model structure with lagged spot prices describes gasoline price behavior at the national and all regional levels, it implies marketing behavior has major similarities in all regions. Third, since the national model is not a simple linear combination of regional models, some interaction between regions occurs. This paper also suggests areas of interest for gasoline price model development. In particular, the breakdown between aggregated regional distinctions and national price pass-through in this paper indicates that regional models may not necessarily provide the best national estimate.

While price pass-through, in general, and gasoline price pass-through, in particular, have been investigated extensively, further work may still improve understanding of the empirical characteristics of asymmetry, which in turn, may lead to improved understanding of market behavior and improved model structures. The implications of pattern asymmetry for consumer and retailer welfare and the possibility of improving upon the performance of gasoline price forecasting models by incorporating pattern asymmetry also remain to be explored. Since it is generally recognized that the gasoline market experienced a regime change in 2000, additional work would include exploring if pass-through conclusions concerning asymmetry, speeds, regional differences, and aggregation issues drawn in this paper hold under different regimes and time periods. More generally, potential issues of temporal aggregation may need to be addressed.[14] Also, frequency of data might affect results. The current model uses weekly average spot prices. This could lead to inferior results when there is a significant price shift during the week, masked by the weekly average. Thus, using a model with daily spot prices may provide improved explanation of retail price variation, although the noise of the daily data could also have the opposite effect. Additionally, the U.S. GAO has reported that the impact of large spot-price movements may be different from the more typical small movements [U.S. GAO, 1993]; separating the two may provide increased explanatory power. The approach developed here may also provide a structure to investigate price pass-through behavior for other energy commodities, such as diesel fuel, heating oil, and propane.

APPENDIX A

Detail of Estimated OLS Regression Coefficients

Table A.1 shows the estimation results for the period from April 3, 2000 to December 29, 2003. Binary variables are used to remove the impact of unusual market movements in the following weeks (retail price dates): May 7, 2001—near peak price for 2001 (then an all-time record), when retail prices on the West Coast continued sharply upward and pass-through suggested they should slow; July 22, 2002—PADD 4, when retail prices rose much more sharply than expected; and August 25 and September 1, 2003—near record price peak, when PADD 1a and 1b retail prices rose much more sharply than expected. In each case, removal of the outlier data point significantly improved the standard errors. The dummy variable, dpad4/5, refers to the difference in spot prices between PADD 4 and PADD 5.

TABLE A.1

	Coef./Sig.									
	PADD 1	PADD 1A	PADD 1B	PADD 1C	PADD 2	PADD 3	PADD 4	PADD 5	CA	U.S.
$\Delta^+\mathrm{SPOT}_{t-1}$	0.422***	0.215***	0.293***	0.487***	0.740***	0.488***	0.158***	0.314***	0.355***	0.566***
$\Delta^+\mathrm{SPOT}_{t-2}$	0.243***	0.144***	0.168***	0.241***	0.188***	0.216***	0.267***	0.132***	0.127***	0.210***
$\Delta^+\mathrm{SPOT}_{t-3}$	0.127***	0.069**	0.115***	0.107***	−0.109*	0.099***	0.159***	0.052*	0.030	0.116***
$\Delta^+\mathrm{SPOT}_{t-4}$	0.051*	0.043	0.062**	0.005	0.091*	0.019	0.105***	0.056*	0.051	
$\Delta^+\mathrm{SPOT}_{t-5}$				−0.030		−0.024	0.045*	−0.001	0.007	
$\Delta^+\mathrm{SPOT}_{t-6}$				0.070**		0.051*	0.045*	−0.007	0.001	
$\Delta^+\mathrm{SPOT}_{t-7}$				0.062*		0.061**	0.037	0.048	0.052	
$\Delta^+\mathrm{SPOT}_{t-8}$				0.017		0.031	0.050*	0.026	0.032	
$\Delta^+\mathrm{SPOT}_{t-9}$				0.072**		0.102***		0.083***	0.084**	
$\Delta^+\mathrm{SPOT}_{t-10}$								0.028	0.064*	
$\Delta^+\mathrm{SPOT}_{t-11}$								0.103***	0.101***	
$\Delta^-\mathrm{SPOT}_{t-1}$	0.144***	0.129***	0.114***	0.192***	0.464***	0.173***	0.166***	0.110***	0.106***	0.285***
$\Delta^-\mathrm{SPOT}_{t-2}$	0.132***	0.010	0.071*	0.176***	0.249***	0.194***	0.114***	0.093**	0.089*	0.155***
$\Delta^-\mathrm{SPOT}_{t-3}$	0.126***	0.010	0.068**	0.203***	0.122***	0.173***	0.076**	0.108***	0.113**	0.094***
$\Delta^-\mathrm{SPOT}_{t-4}$	0.081***	0.008	0.050*	0.122***	0.027	0.123***	0.055*	0.131***	0.149***	0.078***
$\Delta^-\mathrm{SPOT}_{t-5}$	0.120***	0.073**	0.069**	0.165***	0.057*	0.172***	0.068**	0.180***	0.202***	0.127***
$\Delta^-\mathrm{SPOT}_{t-6}$	0.083***	0.057**	0.080***	0.061**		0.094***	0.056**	0.158***	0.185***	0.062**
$\Delta^-\mathrm{SPOT}_{t-7}$	0.061***	0.056**	0.062***	0.041		0.026	0.087***	0.151***	0.166***	0.070**
$\Delta^-\mathrm{SPOT}_{t-8}$	0.070***	0.049**	0.067***	0.053*		0.042	0.053**	0.079***	0.091***	0.036
$\Delta^-\mathrm{SPOT}_{t-9}$	0.069***	0.041**	0.041**	0.039		0.016	0.034	0.066***	0.067**	0.037

Δ^{-}SPOT$_{t-10}$	0.043**	0.050**	0.034*	0.037		0.058**	0.036			−0.012
Δ^{-}SPOT$_{t-11}$		0.053**	0.040*	0.042		0.045*	0.032			0.072***
Δ^{-}SPOT$_{t-12}$		0.042**	0.043**				0.056**			
EC$^{+}{}_{t-1}$	−0.031	−0.123**	−0.068	−0.028	−0.113	−0.041	−0.050	0.024	0.022	−0.006
EC$^{-}{}_{t-1}$	−0.100***	−0.212***	−0.142***	−0.121***	−0.152**	−0.104***	−0.042	−0.126***	−0.146***	−0.102***
d25aug03	5.712***	10.7369***	8.358***							
d01sep03		2.291***	2.066**							
dpad4/5$_{t-1}$							−0.039***			
dpad4/5$_{t-1}$							−0.058***			
dpad4/5$_{t-1}$							−0.051***			
dpad4/5$_{t-1}$							−0.047***			
dpad4/5$_{t-1}$							−0.047***			
dpad4/5$_{t-1}$							−0.033**			
dpad4/5$_{t-1}$							−0.028**			
dpad4/5$_{t-1}$							−0.019			
d22jul02							4.531***			
d7may01								5.444***		5.476***
AR(1)	0.314***	0.674***	0.586***		−0.452***		0.403***	0.508***	0.507***	
Adj. R^2	88.0%	88.0%	88.2%	84.2%	87.5%	86.2%	81.6%	84.3%	79.6%	88.3%
S.E.	0.838	0.820	0.787	1.105	1.836	0.992	1.078	1.371	1.784	1.045
Estimation										
D.W.	1.977	1.966	2.066	1.938	1.965	1.977	1.933	2.060	2.027	2.104

Notes: Conventionally, * indicates the 90 percent, ** the 95 percent, and *** the 99 percent levels.

APPENDIX B

Relationship Between Coefficients β's and γ's

This appendix demonstrates a little known fact that the coefficients on spot price changes (i.e., β's) and on the error correction model (ECM) term (i.e., γ's) address related but different types of price adjustments. The β's reflect the change in retail price corresponding to a change in spot price, with β^{+} for a spot price increase and β^{-} for a decrease, while the γ's reflect the price response to the retail price being above (γ^{+}) or below (γ^{-}) the long-run equilibrium. All β coefficients are expected to be positive because the retail response is in the same direction as the spot price change, i.e., retail prices rise when spot prices increase and retail prices decline when spot prices decrease. As defined from the long-run equilibrium relationship in the Engle–Granger ECM methodology, the γ coefficients are expected to be negative, indicating a response towards long-run equilibrium.

Figure B.1 shows that retail price response lags changes (up or down) in spot prices. This lagged response being the case, the value of the ECM term becomes negative during a retail price run-up (actual retail prices below the long-run value) and positive when retail prices are declining after their peak value (actual retail prices above the long-run value).

Figure B.2 shows the relationship between retail prices and the ECM term. When retail prices are lower than their long-run equilibrium value, the retail prices (the thin line) are rising and the ECM term (the thick line) is negative; see, for example, the segments immediately before 3/17/2003 and 8/25/2003 indicated by the vertical lines. The opposite occurs when retail prices are above the long-run equilibrium. Thus, negative values of the ECM term (and the associated γ^{-} coefficient) are associated with rising prices and the β^{+} coefficients. Additionally, $|\gamma^{+}| < |\gamma^{-}|$ implies that the immediate adjustment to being out of long-run equilibrium, which is in the opposite direction to the current price movements, is slower when retail prices are falling. The smaller $|\gamma^{+}|$ implies a slower immediate downward adjustment towards the long-term equilibrium when retail price is above the long-term equilibrium, while the larger $|\gamma^{-}|$ implies faster immediate adjustment when retail price is below the long-term equilibrium. Thus, the coefficients on the ECM term also can be used to indicate the existence and direction of pattern asymmetry.

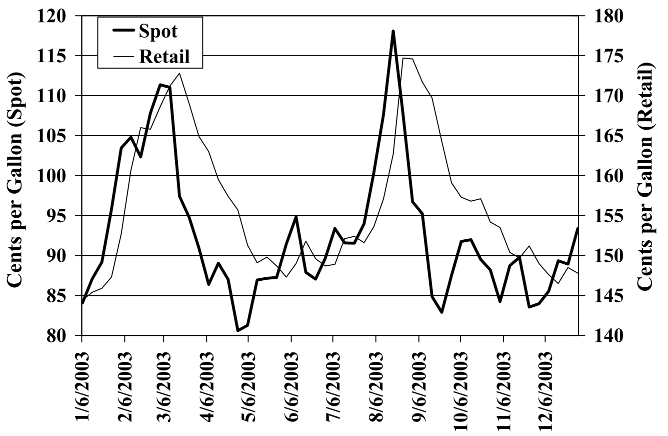

FIGURE B.1. Comparison of U.S. Spot and Retail Prices in 2003.

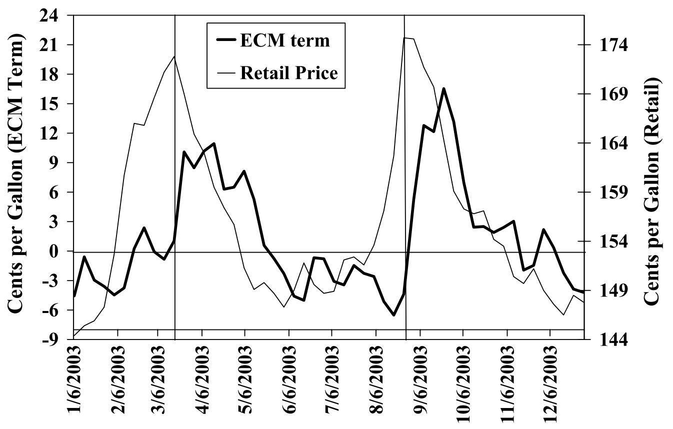

FIGURE B.2. Retail Price and ECM Term in 2003.

Footnotes

1 Descriptions of the gasoline market in the United States can be found in Appendix C of *Inquiry into August 2003 Gasoline Price Spike* [Shore and MacIntyre, 2003].

2 There are, however, studies for individual regions and studies with data collected from multiple locations. For example, Godby et al. [2000] studied crude oil price pass-through to gasoline price in 13 Canadian cities.

3 Definitions of the five PADDs and three subregions in PADD 1 can be found in Appendix B of *Inquiry into August 2003 Gasoline Price Spike* [Shore and MacIntyre, 2003].

4 Throughout this analysis, prices for regular grade, representing about 80 percent of all sales, are used exclusively. Differential pricing for mid-grade and premium gasoline is often influenced by marketing considerations outside the scope of this work.

5 Exact formulae are available upon request. See also Table 2 in Burdette and Zyren [2003].

6 Empirical evidence shows that the margin between spot and retail gasoline prices is relatively constant over time. If amount symmetry did not hold, then the spot to retail margin would continually increase or decrease over time.

7 Dickey–Fuller tests for data in early 1990s show that both spot and retail gasoline price time series have a unit root, and Johansen tests show that there is a single cointegrating relationship between spot and retail prices. These results are consistent with the standard findings in the literature [Borenstein et al., 1997; also Godby et al., 2000]. However, in the period since January 2000, Dickey–Fuller tests fail to show a unit root in gasoline prices. Detailed tests results are available upon request. Other investigators [Asplund et al., 2000; Goodwin and Holt, 1999] have also encountered similar issues when studying pass-through in other commodities.

8 ARMA terms and binary variables to remove unique market events are added when necessary.

9 To a first approximation, the model formulation can be assumed to be a first-order difference equation. As such, it can be easily shown that the first lag in equation (1) is the pass-through speed.

10 See Appendix B for further discussion on the interrelationship between β's and γ's.

11 More precisely, $\beta_i^+ = \beta_i^-$ if $i \leq \min(k^+, k^-)$ and $\beta_i^+ = 0$ if $k^+ > k^-$.

12 California and PADD 5 have $k^+ > k^-$; thus, the negative coefficients are set to zero.

13 Parsely [2001] studied various sectors in Japanese industry and also found different results at sector level *versus* at the aggregated.

14 Bachmeier and Griffin [2003] used daily data and discussed aggregation bias. They concluded that there is no asymmetry. Finally, their out-of-sample forecasts shows better results than Borenstein et al. [1997], and that the symmetric models are better than the asymmetric one.

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