January 2018

Crude petroleum prices and retail fuel margins: an empirical examination

This study uses error-correction models to analyze the response of retail automotive fuel margins to changes in crude petroleum prices. The results show a large, negative contemporaneous response of retail automotive fuel margins to changes in crude petroleum prices. The negative contemporaneous response is found to hold equally in cases where crude petroleum prices are rising or falling.

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In March 2009, the Producer Price Index program (PPI) of the U.S. Bureau of Labor Statistics introduced a price index measuring the average monthly change in retail automotive fuel margins. Retail fuel margins are defined as the retail price of automotive fuels less the acquisition costs of the fuels.[1] The PPI also publishes a monthly index measuring the average change in prices for crude petroleum. The addition of the PPI for retail fuel margins facilitates analysis of the relationship between crude petroleum prices and retail fuel margins. The study presented in this article uses econometric techniques to analyze the behavior of retail fuel margins in response to changes in crude petroleum prices.

Many authors have analyzed the relationships between prices for crude petroleum, wholesale gasoline, and retail gasoline. In doing so, the authors can make indirect inferences as to how retail margins react to changes in prices earlier in the chain of gasoline production. For example, if retail gasoline prices are found to respond slowly to increases in wholesale gasoline prices, one could infer that retail margins are shrinking. This study differs from previous studies in that it measures the response of retail fuel margins to changes in crude petroleum prices *directly* by examining the relationship between the PPI for crude petroleum and the PPI for automotive fuel retailing (an index directly measuring changes in retail fuel margins). This analysis is, however, similar to many earlier studies in that it focuses on examining the relationship between retail fuel margins and the prices at the earliest (crude) stage of petroleum product production.

Most studies of price transmission within the gasoline production chain focus on determining whether there are asymmetric price transmission relationships within the chain; that is, whether gasoline prices respond differently to rising versus falling earlier-stage petroleum price changes. These studies have had mixed results, with only some identifying asymmetric price transmission. Karrenbrock examines the relationship between wholesale and retail gasoline prices and finds that both wholesale gasoline price increases and decreases are eventually passed on fully to retail gasoline prices, but that wholesale price increases are passed along more rapidly than wholesale price declines.[2] Borenstein, Cameron, and Gilbert estimate a set of error-correction models to examine asymmetric price transmission at differing stages of petroleum production and distribution. The authors find asymmetry, particularly between wholesale and retail gasoline prices.[3] Bachmeier and Griffin estimate an error-correction model with daily spot gasoline and crude petroleum price data from 1985 through 1998 and find no evidence of asymmetric price pass through.[4] Using an error-correction model, Ye, Zyren, Shore, and Burdette examine five U.S. regions and find asymmetric spot-to-retail price pass-through patterns in all regions.[5] Balke, Brown, and Yucel use both a levels specification and an error-correction specification to examine asymmetric price transmission within the petroleum production chain and find their results are sensitive to the specification, with the levels specification indicating little asymmetry and the error-correction specification suggesting strong asymmetry.[6] Although not examining asymmetric price transmission, Weinhagen used a vector autoregression model to show that crude petroleum based supply shocks explain the majority of movement in consumer gasoline prices.[7]

In contrast to previous studies that measure the response of gasoline *prices* to changes in crude petroleum prices, this analysis measures the response of retail fuel *margins* to changes in crude petroleum prices. The main finding of this study is that retail fuel margins respond negatively to changes in petroleum prices, indicating that rising (falling) crude petroleum prices lead to falling (rising) retail fuel margins. The study does not find evidence of asymmetric price transmission from crude petroleum prices to retail fuel margins.

The next section of the article describes how standard and asymmetric error correction models can be used to examine the behavior of retail fuel margins in response to changes in crude petroleum prices. The third section applies the methodology to the PPIs for crude petroleum and automotive fuel retailing. The final section concludes the paper.

Methodology

This study examines the relationship between crude petroleum prices and retail gas margins by estimating standard and asymmetric error-correction models. Error-correction models are appropriate to use when the set of nonstationary time series being modeled shares a common long-run stochastic trend, a situation known as cointegration.[8] More formally, a set of nonstationary time series is considered cointegrated when a linear stationary combination of those series exists.[9] Error-correction models describe changes in a dependent variable as a function of changes in lagged values of itself, changes in current and lagged values of the variable(s) it shares a common trend with, and deviations from the common trend.[10]

Standard error-correction model

The standard error-correction model as applied to retail fuel margins and crude petroleum prices can be written as follows:

(1) $$\Delta \mathrm{MF}_t = \beta_0 + \sum_{i=0}^{k} \beta_{ci} \Delta \mathrm{PC}_{t-i} + \sum_{j=1}^{n} \beta_{mj} \Delta \mathrm{MF}_{t-j} + \beta_z \mathrm{ECT}_{t-1} + \varepsilon_t,$$

where

- $\Delta \mathrm{MF}_t$ is the first difference in the PPI for retail automotive fuel margins at time *t*;
- $\Delta \mathrm{PC}_{t-i}$ is the first difference in the PPI for crude petroleum at time *t-i*; and
- ECT_{t-1} is the error-correction term, which measures the long-run disequilibrium between retail automotive fuel margins and crude petroleum prices. The error correction term is estimated as

(2) $$\mathrm{ECT}_{t-1} = \mathrm{MF}_{t-1} - \gamma_0 - \gamma_1 \mathrm{PC}_{t-1},$$

where ε_t is the error term at time *t*.

The sum of the β_{ci} coefficients measures the impact of crude petroleum price changes on current retail automotive fuel margins, and the sum of the β_{mj} coefficients measures the impact of lagged retail automotive fuel margins on current retail automotive fuel margins. β_z is the long-run adjustment parameter.

Asymmetric error-correction model

The basic error-correction model can be modified to allow for asymmetry by including separate variables accounting for positive and negative changes in crude petroleum prices, as well as including separate variables accounting for instances in which automotive fuel margins are above and below their long-run equilibrium model.[11] The following equation represents the asymmetric error-correction model:

(3) $$\Delta \mathrm{MF}_t = \beta_0 + \sum_{i=0}^{k^+} \beta_{ci}^+ \Delta^+ \mathrm{PC}_{t-i} + \sum_{i=0}^{k^-} \beta_{ci}^- \Delta^- PC_{t-i} + \sum_{j=1}^{n} \beta_{mj} \Delta \mathrm{MF}_{t-j} + \beta_z^+ \mathrm{ECT}_{t-1}^+ + \beta_z^- \mathrm{ECT}_{t-1}^- + \varepsilon_t$$

where

- $\Delta^+ \mathrm{PC}_{t-i}$ is the first difference in the PPI for crude petroleum at time *t-i* in cases where the difference is positive and is otherwise zero,
- $\Delta^- \mathrm{PC}_{t-i}$ is the first difference in the PPI for crude petroleum at time *t-i* in cases where the difference is negative and is otherwise zero,
- ECT_{t-1}^+ is the error-correction term at time *t*-1 in cases where the automotive retail fuel margins are above their equilibrium level and is otherwise zero, and
- ECT_{t-1}^- is the error-correction term at time *t*-1 in cases where the automotive retail fuel margins are below their equilibrium level and is otherwise zero.

The asymmetric error-correction model can be used to test for two separate types of asymmetry: amount asymmetry and pattern asymmetry.[12] Amount asymmetry occurs when the average change in automotive retail fuel margins for falling versus rising crude petroleum price differs. A formal test of amount asymmetry using the asymmetric error-correction model is a test of the following null hypothesis:

(4) $$\sum_{i=0}^{k^+} \beta_{ci}^+ = \sum_{i=0}^{k^-} \beta_{ci}^-.$$

Rejection of this null hypothesis would indicate amount asymmetry.

The second type of asymmetry, pattern asymmetry, is present if the timing of retail automotive fuel margins adjustments in response to falling versus rising crude petroleum prices differs. In terms of the asymmetric error-correction model, pattern asymmetry is indicated if any of the following conditions do not hold:

(5) $\beta_{ci}^{+} = \beta_{ci}^{-}$ for some *i*,

(6) $\beta_{z}^{+} = \beta_{z}^{-}$, and

(7) $k^{+} = k^{-}$.

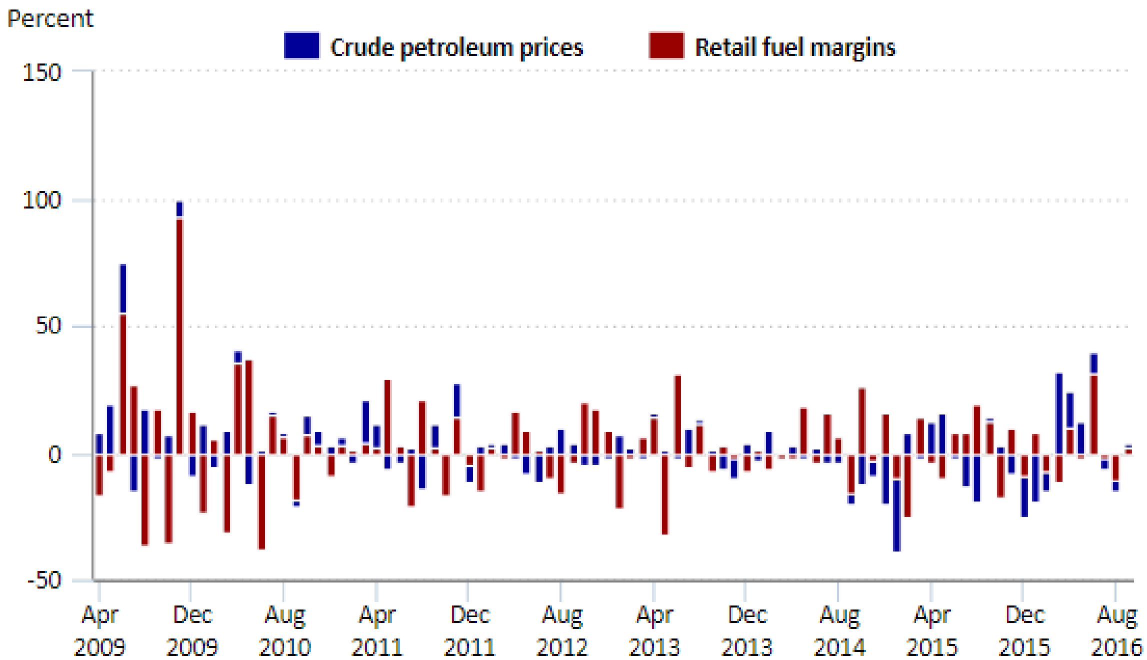
In the case where equation (5) does not hold, pattern asymmetry is present because the response of retail fuel margins to positive and negative changes in crude petroleum prices is not of equivalent size at one or more lags. Pattern asymmetry is present if equation (6) does not hold because retail automotive fuel margins do not return to their long term trend at the same rate in response to positive and negative deviations from the trend. Finally, if equation (7) does not hold, pattern asymmetry is present because the timing of response of retail automotive fuel margins to positive and negative changes in crude petroleum prices differs.

Data and results

Data

Before applying the formal econometric methodology described in the previous section, I examined the data to determine if there is a noticeable visual relationship between crude petroleum prices and retail fuel margins. Figure 1 presents the 1-month percent changes in producer price indexes for crude petroleum and retail fuel margins from April 2009 through September 2016. The data are presented using a stacked bar graph, where the magnitude of percent change in crude petroleum prices is equal to the length of the blue bar, and the magnitude of percent change for retail fuel margins is equal to the length of the red bar. For months in which crude petroleum prices and retail fuel margins are moving in opposite directions, the red and blue bars are located on opposite sides of the zero value on the vertical axis. For months in which the two series move in the same direction, both bars fall on the same side of the zero value on the vertical axis.

Figure 1. Crude petroleum prices versus retail fuel margins, month-over-month percent change in producer price indexes, April 2009 through September 2016



Source: Author's calculations from the producer price indexes for crude petroleum and retail fuel margins. Producer Price Index, U.S. Bureau of Labor Statistics.

Visually, crude petroleum prices and retail fuel margins appear to often move in opposite directions. Crude petroleum prices and retail fuel margins move inversely in approximately 66 percent of months from April 2009 September 2016. In a pronounced example, the indexes for crude petroleum prices and retail fuel margins move in opposite directions in every month from March 2012 through March 2013. Visual analysis therefore suggests that there may be a negative relationship between crude petroleum prices and retail fuel margins. The next subsection more formally examines this relationship using the econometric techniques presented in the methodology section.

Econometric results

In order to ensure that an error-correction model is appropriate for examining the relationship between crude petroleum prices and retail fuel margins, a Johansen cointegration test was performed. The Johansen cointegration test is a multistage test that can be used to determine whether a set of variables is cointegrated and the number of cointegrating relationships the variables share. (The maximum number of cointegrating relationships for a set of series is one less than the number of series included in the set.) The null hypothesis for the first stage of the test is that there are no cointegrating relationships. A large test statistic rejects the null hypothesis and indicates that the series are cointegrated. If the null hypothesis in the first stage of the test is rejected, a second null hypothesis, that there is no more than one cointegrating relationship, is tested. Again, a large test statistic rejects the second null hypothesis and indicates that there is more than one cointegrating relationship. For the two-variable case, the test would end after the second stage because there cannot be more than one cointegrating relationship.[13]

The Johansen test was performed on the PPIs for retail automotive fuel margins and crude petroleum using monthly data from March 2009 through September 2016. (PPI began publishing an index for retail fuel margins in March 2009.) The test included two lags of the differenced endogenous variables and an intercept. Modification to the number of lags included in the test does not change the test results, and neither does inclusion or exclusion of a trend and intercept. On the basis of both the trace and maximum eigenvalue tests statistics, the Johansen cointegration test indicates that the PPIs for retail automotive fuel margins and crude petroleum are cointegrated. Consequently, an error-correction model can be used to examine the relationship between the two cointegrated series. The results of the cointegration test are presented in table 1.

Table 1. Johansen cointergration test results

Hypothesized number of cointergrating equations	Trace statistic			Maximum eigenvalue statistic		
	Test statistic	Critical value	*P*-value	Test statistic	Critical value	*P*-value
None	20.65	15.49	0.0076*	20.07	14.26	0.0054*
At most 1	0.57	3.84	0.4493	0.57	3.84	0.4493

Note: * denotes rejection of the hypothesis at the 0.05 level.

Source: Author's calculations from the producer price indexes for crude petroleum and retail fuel margins. Producer Price Index, U.S. Bureau of Labor Statistics.

After determining that the PPIs for retail fuels margins and crude petroleum are cointegrated, the error-correction model described in equation (1) was estimated using ordinary least squares with monthly data from March 2009 through September 2016. Information criteria were used to determine the optimal lag structure for the error-correction model, and statistically insignificant variables were removed from the model.[14] The results from estimation of the standard error-correction model described are presented in table 2.

Table 2. Standard error-correction model, dependent variable: ∆MFt

Regressor	Coefficient	Standard error	*t*-statistic	Probability
C	0.819	2.076	0.394	0.6943
ΔCP_t	-.637	.123	-5.198	.0000
ECT_{t-1}	-.508	.083	-6.145	.0000

Additional statistics:

R-squared	.358
Durbin-Watson statistic	2.008
F-statistic	24.289
Probability (*f*-statistic)	.000
Akaike information criterion	8.831
Schwarz criterion	8.915

Source: Author's calculations from the producer price indexes for crude petroleum and retail fuel margins. Producer Price Index, U.S. Bureau of Labor Statistics.

Parameters from the error-correction model indicate a large negative contemporaneous response in retail fuel margins to changes in crude petroleum prices. The model therefore implies that when crude petroleum prices rise, retail fuel margins shrink in the same month and that when crude petroleum prices fall, retail fuel margins grow in the same month. Additional specifications of equation (1) that included lagged values of changes in crude petroleum prices and lagged values of the dependent variable were estimated, but in no case were lagged values of crude petroleum or of the dependent variable found to statistically affect retail automotive fuel margins.

A common problem with time series models is that their residuals are correlated with their own lagged values. When this condition, known as serial correlation, is present, ordinary least squares estimation is no longer efficient, standard errors as typically calculated are no longer correct, and, if there are lagged dependent variables, least squares estimates are biased.[15] The Durbin-Watson test statistic, which measures the linear association between adjacent residuals from a regression model, can be used to test for first-order autocorrelation. A Durbin-Watson test statistic of approximately 2 indicates no first-order autocorrelation.[16] To test for higher order serial correlation, Q statistics from a correlogram of the regression's residuals can be computed. If there is no serial correlation in the residuals, Q statistics for all lags should be insignificant.[17] The Durbin-Watson statistic of 2.008 from the standard error-correction model estimated above does not indicate first-order serial correlation of the residuals, and Q statistics from a correlogram of residuals do not indicate higher order serial correlation.

The standard error-correction model suggests that retail fuel margins respond contemporaneously and negatively to changes in crude petroleum prices but cannot be used to examine whether fuel margins respond asymmetrically to changes in crude petroleum prices. To examine the issue of asymmetry, the asymmetric error-correction model presented in equation (3) was estimated. Again, information criteria were used to determine the optimal lag structure of the model, and insignificant variables were removed from the model. The results of this estimation are presented in table 3.

Table 3. Asymmetric error-correction model, dependent variable: ΔMFt

Regressor	Coefficient	Standard error	*t*-statistic	Probability
C	2.078	4.282	0.485	0.6287
ΔCP_{t+}	-.520	.244	-2.130	.0360
ΔCP_{t-}	-.737	.212	-3.477	.0008
$ECT_{t-1}+$	-.663	.164	-4.033	.0001
$ECT_{t-1}-$	-.386	.135	-2.870	.0052

Additional statistics:

R-squared	.370
Durbin-Watson statistic	2.011
F-statistic	12.483
Probability (*f*-statistic)	.000
Akaike information criterion	8.857
Schwarz criterion	8.996

Source: Author’s calculations from the producer price indexes for crude petroleum and retail fuel margins. Producer Price Index, U.S. Bureau of Labor Statistics.

Parameters from the asymmetric error-correction model indicate a large negative contemporaneous response in retail fuel margins to both increases and decreases in crude petroleum prices. Also, both the positive and negative error-correction terms are statistically significant. As with the standard error-correction model, additional specifications of the asymmetric error-correction model were estimated. These additional specifications included lagged values of positive and negative changes in crude petroleum prices as well as lagged values of the dependent variable, but in no case were these additional variables found to be significant. Again, the Durbin-Watson statistic does not indicate first-order serial correlation, and Q statistics from a correlogram of residuals do not indicate higher-order serial correlation.

To determine whether there is amount asymmetry—differing responses in retail fuel margins to positive versus negative changes in crude petroleum prices—a Wald test was conducted based on the null hypothesis of no amount asymmetry as presented in equation (4). Wald tests measure the extent to which the unrestricted estimates fail to satisfy the restrictions of the null hypothesis. A small *p*-value (generally ≤ 0.05) of the Wald statistic rejects the null hypothesis of no amount asymmetry. A large *p*-value (generally > 0.05) of the Wald statistic implies that the null hypothesis is not rejected.[18] The Wald test could not reject the null hypothesis of no amount asymmetry. On the basis of the null hypotheses of no amount asymmetry, the p-value of the Wald statistic is 0.572.

In addition to amount asymmetry, the asymmetric error-correction model was used to test for pattern asymmetry. However, on the basis of the lag structure of the model presented in table 3, only limited testing for pattern asymmetry was possible. Equation (5) indicates that pattern asymmetry is present if the coefficients for the positive versus negative crude petroleum variables differ significantly at any lag. Because only current period crude petroleum prices (for both the positive and negative variables) were found to be significant, this test becomes irrelevant. Likewise, the test presented in equation (7), that the lag structure of positive versus negative crude petroleum prices differs, also becomes irrelevant. The test that retail fuel margins do not return to their long term trend at the same rate in response to positive and negative deviations from the trend, as presented in equation (6), however, is still relevant. A Wald test was therefore conducted using the null hypothesis that the coefficients of the positive and negative error-correction terms are equivalent. The Wald test (with a p-value of the Wald statistic of 0.268) could not reject the null hypothesis of no pattern symmetry presented in equation (6).

Conclusion

The study presented in this paper used the PPIs for crude petroleum and retail automotive fuel margins to analyze the behavior of retail automotive fuel margins in response to changes in crude petroleum prices. The study began by testing for cointegration between the PPIs for crude petroleum and retail automotive fuel margins. On the basis of test statistics from the Johansen cointegration test, the two series were found to be cointegrated. Given that the series are cointegrated, a standard vector error-correction model was estimated. Coefficients from the standard vector error-correction model indicate a large negative contemporaneous response in retail fuel margins to changes in crude petroleum prices. Next, an asymmetric vector error correction model was estimated to examine whether retail fuel margins behave asymmetrically in either amount or pattern to positive versus negative changes in crude petroleum prices. Wald tests did not support the notion of either amount or pattern asymmetry.

Because of the lack of asymmetry detected, the standard vector error-correction model is likely superior to the asymmetric vector error-correction model for understanding the behavior of retail fuel margins in response to changes in crude petroleum prices. Additionally, both the Akaike and Schwarz information criteria suggest that the standard error-correction model is superior to the asymmetric error-correction model. The results of this study therefore imply that rising (falling) crude petroleum prices lead to shrinking (growing) margins in that same month, and that there is not an asymmetry in the response of retail automotive fuel margins to rising versus falling crude petroleum prices.

This study is intended not to explain the economic reason for the observed relationship between automotive fuel margins and changes in crude petroleum prices, but rather to empirically estimate the relationship. There is, however, literature on consumer search theory that may help explain the observed negative response of automotive fuel margins to changes in crude petroleum prices. For example, in 2004, Lewis developed a consumer search model that predicted consumers search for products less when prices are falling and more when prices are rising.[19] If this is the case, consumers are more willing to seek out lower priced products when prices are rising, causing an increase in competition among retailers. This increase in competition then leads to lower profit margins for retailers. In cases where prices are falling, the opposite would occur and profit margins would grow.

SUGGESTED CITATION

Jonathan C. Weinhagen, "Crude petroleum prices and retail fuel margins: an empirical examination," *Monthly Labor Review,* U.S. Bureau of Labor Statistics, January 2018, https://doi.org/10.21916/mlr.2018.2

NOTES

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