THE WEST TEXAS INTERMEDIATE CRUDE OIL PRICE PASS – THROUGH SINCE THE APPLICATION OF SLICKWATER FRACTURING

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ABSTRACT

This study utilizes an Autoregressive Distributed Lag model to investigate the nature of the West Texas intermediate (WTI) crude oil price pass-through in the era of slickwater fracturing. The empirical results reveal a very high short-run pass-through rate from the weekly Cushing, OK per gallon WTI spot price FOB to the per gallon Gulf Coast price of regular gasoline of 0.8703520 and an overshooting long-run pass-through rate of 1.1332508 which is consistent with figures reported in existing literature . The bounds test results indicate a long-term relationship between the weekly Cushing, OK per gallon WTI spot price FOB and the per gallon Gulf Coast price of regular gasoline. The empirical findings further suggest that gasoline wholesalers in the Gulf Coast region considered their selling price four weeks back in determining their current selling price; while suppliers took up to three weeks to respond to the shock in crude oil price fluctuations completely. **JEL classification:** Q4

INTRODUCTION

Crude oil, by virtue of its high energy density, has long been the source of power that propels the industrial world forward. Its chief derivative in modern times, gasoline, directly or indirectly affects nearly every aspect of any modern industrial economy. Fluctuations in gasoline prices not only directly affect the pocketbooks of consumers; they also affect what cars they buy, what vacations they take, and how far from work they choose to live. Central bankers in turn are concerned with the effects of gasoline prices on inflation expectations, consumer spending, and consumer confidence (Yellen, 2001). The recent upheaval in gasoline prices "at the pump" has resulted in much attention being directed towards how the gasoline market functions, and how gasoline prices are determined.

Since the industrial revolution, the demand for petroleum-based fuels and lubricants has remained largely inelastic. Given this inelasticity, prices are disproportionately determined by any change in supply, and therefore acutely subject to supply disruptions. In turn, higher petroleum prices result in cost-push inflation, thereby reducing the real income and purchasing power of consumers, as well as squeezing business profit margins. Because of inherent regressivity, these results often result in an exaggerated negative income effect on the low-income segment of the population. Historically, due to the net-import nature of U.S. petroleum sourcing, high energy prices negatively affect the trade balance, the value of the U.S. dollar, and the political and economic security of the nation.

As discussed in the following review of literature, the gasoline price is affected by both the demand and supply sides of the market. On the supply side, programs such as the U.S. ***Windfall Profits Tax Act in 1980***, which among other things created the Section 29 production tax credit for unconventional natural gas facilitated the introduction of slickwater fracturing to the oil and gas industry and led to a drastic increase in the U.S. production of oil and gas, which in turn reduces the U.S. import of crude oil. On the demand side, the recent U.S. subprime mortgage crisis and the European sovereign debt crisis caused economic recession around the globe, slowing down the demand for gasoline in the international market. These aforementioned in turn depress the crude oil prices. Therefore, it is of substantial interest to study the nature of the crude oil price pass-through in the Gulf Coast since the application of slickwater fracturing technology in oil and gas production.

The remainder of this study begins with a review of literature; following this is the discussion of the methodology and the model specification; the next section describes the data set to be used in the analysis and a summary of its descriptive statistics; the following section summarizes the estimation results; the section that follows discusses the empirical findings; finally, the las section provides some concluding remarks.

REVIEW OF LITERATURE

Although multiple variables explain gasoline price fluctuations, studies indicate that the primary explanation is changes in the price of oil (Chouinard & Perloff, 2002; Ginn & Gilbert, 2009); however, responses of the gasoline price to oil price changes vary. Most studies found gasoline price adjustments are asymmetric and caused by oil price shocks (Chen, Finney, and Lai, 2005; Deltas, 2008). One explanation for the asymmetric response is that there is less consumer sensitivity towards gasoline prices when prices are falling and therefore less incentive for gasoline stations to lower their price (Lewis, 2011). Honarvar (2009) employs a hidden cointegration technique to examine gasoline price asymmetry and the results indicate asymmetric gasoline price adjustments to an oil price shock.

Two recent papers, however, find weak evidence of asymmetric gasoline price adjustment. Douglas (2010) considers a threshold model and concludes that any asymmetric evidence in the results is influenced by a few outlying observations whereby the retail gasoline prices generally respond symmetrically to gasoline spot prices. Grasso and Manera (2007) also employ threshold and momentum threshold models to explore the relationship between gasoline prices and oil prices in five European countries. Asymmetries are found, but most of the asymmetric adjustment occurs at ***the distribution stage***- they find mixed evidence of long-run asymmetric adjustment in the retail gasoline price following oil price shocks.

Chesnes (2012) argued that the literature has not only focused on the ability of firms to successfully capture rents when input costs change, but also on how the rate of pass-through varies when the costs increase. In the gasoline industry, this asymmetric phenomenon is known as *rockets and feathers*. Much of the extant literature comes to seemingly contradictory conclusions about the existence of this phenomenon, though the differences may be due to different data sources, price series, aggregation over time and across geographic areas, as well as misspecified models.

The gasoline industry has been the focus of a particularly large amount of research on pass-through for several reasons. Gasoline is a homogeneous product and both retail and intermediate wholesale prices are relatively transparent compared with other industries. Much of the variation in gasoline prices is driven by the price of crude oil, the key input into gasoline. Crude oil is traded on a world market and prices are reasonably transparent to market players and to consumers.

Oil price movements in the 1970s and 1980s had pronounced negative effects not only on the U.S. economy but also on other industrialized economies. As a result, these economies have become less sensitive and more alike in their reactions to changes in crude oil prices. Historically, the high growth rate of the Chinese economy has pushed its demand for crude oil to the second highest level. India would not be far behind China, doubling its oil demand in the last decade (Adkins, 2004; The Economist: Special Report, 2014). If this trend continues, these two emerging economies will significantly affect the international demand for oil, and in the process, alter both global and domestic trade flows. Finally, owing largely to differing tax regimes gasoline prices in Europe are roughly three times higher than in the United States.

On the supply side, Hubbert (1956) predicted that half of the world crude oil has been produced or the oil production would peak in the mid-1990s. Mawdsley and Andrews (2004) concluded that most prolific producing areas such as Gulf of Mexico and the North Sea have already reached their peak levels of production and other major areas such as the Middle East and Russia will be at their peaks in the near future.

As maintained by Osho, et al. (2005), U.S. refineries are operating at their peak capacity because there has not been a new refinery built in the country for the last 30 years with a capacity exceeding 50 Mb/cd. Additionally, the U.S.-EPA's stringent requirements for gasoline limit balancing shipments among the States in many cases preclude import volumes. In 1980, U.S. refining capacity was 18.6 million barrels a day, while in 2005 it dropped to 17 million; however, demand increased to almost 21 million barrels a day*(Wall Street Journal,* September 28, 2005, p. A16). These conditions enhance the probability of downstream supply disruptions.

While crude oil is easier and relatively less costly to store, its derivatives such as jet fuel and gasoline of different grades are much costlier to store. Flexible refining operations allow refiners to adjust cut points and product yields, and may mitigate the impact of seasonal demand for gasoline. However, the volatility of prices of gasoline of all grades is an expected result of the inelasticity of both short-term demand and supply, peak refining capacity limit, the cost and limitations of storing gasoline, and the seasonality in petroleum demand.

Given the current demand-supply of crude oil and the refining conditions in the international arena, including rapidly expanding energy requirements from developing countries, especially China and India, a disruption of crude oil production or refining capacity for any reason, could cause the U.S. gasoline price at the pump to increase drastically. The recent behavior of U.S. gasoline prices lend credence to this contention. For example, the explosion of a small refinery in

West Texas and the announcement by OPEC not to increase its production level sent the U.S. average price of unleaded gasoline at retail up 20 cents per gallon in early February, 2008. Further attesting to the price volatility, within a one year period, gasoline prices have more than doubled before falling by more than half.

An analysis of the supply side of the energy sector suggests that the gasoline market structure is another factor influencing the retail prices of gasoline in the US. The U.S. energy sector is dominated by a few large companies, especially following a spate of horizontal oil company mergers between 1999 and 2001. Five vertically integrated companies-Exxon-Mobil, BR Amoco-Arco, Chevron Texaco, ConocoPhillips, and Marathon control 61% of the U.S. retail gasoline market, 47% of the U.S. refining market, and 41% of the exploration and production market. When the next five largest companies are included, the largest ten companies control 88% of the gasoline market, 70% of the refining market, and 54% of all exploration and production. In this oligopolistic market setting, the pricing strategies of these large oil and gas corporations play an important role in determining the prices of refined products.

Since the Organization of Petroleum Exporting Countries (OPEC) was formed, the volatility of international crude oil prices has sharply increased. This was especially evident in the 1973-1974 crude oil embargo, which sent disruptive supply shocks throughout the energy-dependent industrial world. These disruptions encouraged the creation of the U.S. Strategic Petroleum Reserve in 1975 and the introduction of oil derivatives to the financial markets as a hedge against price volatilities.

Historically, Kuuskra and Guthrie (2002) argued that to promote energy independence, the U.S. government has created many supporting programs such as the ***Windfall Profits Tax Act in 1980***, which among other things created the Section 29 production tax credit for unconventional natural gas, providing an incentive of $0.50 per thousand cubic feet of natural gas produced from unconventional resources.

Additionally, Trembath et al. (2012) posited that while private natural gas companies, particularly Mitchell Energy, did provide substantial in-house R&D to the shale gas commercialization effort, ***federal programs*** were involved along every phase of the innovation pipeline. From early R&D (diamond-studded drill bits, microseismic imaging, directional drilling) to cost-sharing on demonstration projects (the Eastern Gas Shales Project, the subsidization of Mitchell Energy's first horizontal drill in the Barnett) to tax policy support for a pre-commercial industry (the 1980-2002 Section 29 production tax credit for unconventional natural gas resources), federal agencies and policies acted over 25 years to maximize the effect of shale gas research and commercialization.

Though natural gas productions from unconventional reservoirs has been growing since the early 1980's, hydraulic fracturing technology had not advanced or been perfected to the point where full scale commercial deployment was economic without subsidy. Shale gas producers relied on the Section 29 production tax credit, and on developers like Mitchell Energy charging a premium for gas resources. Mitchell energy applied revenue towards in-house R&D throughout the 1980's and in to the 1990's (Yergin, 2011). Hydraulic fracturing with crosslinked gel fluid chemistries was proven successful in the Barnett Shale, but engineers continued optimizing fluid systems to exploit less permeable reservoirs. The elimination of traditional guar-based fluid systems in favor of high-rate slickwater fluids proved to be the key to maximizing gas recovery while still meeting economic targets.

In 1998, Mitchell engineers applied slickwater fracturing to their wells and reduced fracturing job costs down to \$100,000, compared to between \$250,000 and \$300,000 for massive hydraulic fracturing projects (Steinsberger, 2011). Meeting this economic hurdle is widely considered a milestone that pushed shale gas in to full commercial competitiveness. Ever since, U.S. production of oil and gas has increased dramatically, which in turn reduces U.S. imports of crude oil. As an additional historical note, Mitchell Energy was bought by Devon Energy in 2002 for \$3.5 billion, the same year that the Section 29 tax credit was allowed to expire (Yergin, 2011).

METHODOLOGY AND MODEL SPECIFICATION

Structural Break and Its Implication

It is expected that long time series data will experience structural breaks. Failure to account for structural breaks may result in model misspecification which may be one of the possibilities for misspecified models stated by Chesnes (2012). When the structural breaks occur in a major market, usually as result of economic shocks, the government often reacted by certain policy measures. Therefore in reality, there usually is an interaction between the structural break and product price.

To account for possible structural breaks, this analysis defined the spread, denoted by SP_t, as the difference between the two-time series. To search endogenously for the possibility of any structural break in the relationship between the two time series, this study utilized Perron's (1997) endogenous unit root test function with the intercept, slope, and the trend dummy to test the hypothesis that the spread has a unit root.

$$SP_t = \mu + \theta DU + \alpha t + \gamma DT + \delta D(T_b) + \beta SP_{t-1} + \sum_{i=1}^{k} \psi_i \Delta SP_{t-i} + \upsilon_t \qquad (1)$$

me trend; $DT = 1(t > T_b)$ is a post-break slope dummy variable; $D(T_b) = 1(t = T_b+1)$ is the break dummy variable; and ε_t are white-noise error terms. The null hypothesis of a unit root is stated as $\beta = 1$. The break date, T_b, is selected based on the minimum t-statistic for testing $\beta = 1$ (see Perron, 1997, pp. 358-359).

The common methodology to account for a structural break is to introduce a dummy independent variable d_t with the value of 1 from the structural break date onward and 0 elsewhere. In the energy sector, a structural break is usually caused by a shock which precipitates an interaction between structural break and crude oil prices. Let z_t be an independent variable measuring the effect of the interaction between the structural break and crude oil price. Econometrically, if the two regressors d_t and z_t are highly correlated, only z_t is included in the model to account for both structural break and crude oil price precipitated by the shock causing the structural break and to avoid single matrix in the estimation process. In fact, the exploratory analysis suggested that the correlation between z_t and d_t is 93.32 percent, thus, in the model specification, only z_t is included.

Model Specification

To investigate how changes in the price of crude oil are passed on to consumers i.e., the crude oil price pass-through, this study follows Wickens and Breusch (1988) and Pereira and Maia-Filho (2013) to specify and estimate an Autoregressive Distributed Lag [ARDL(n,m,s)] model hypothesizing the relationship between the endogenous variable gas_t, the independent variables wti_t and z_t.

$$gas_t = \mu + \sum_{j=1}^{n} \beta_j gas_{t-j} + \sum_{k=0}^{m} \delta_k wti_{t-k} + \sum_{l=0}^{s} \rho_l z_{t-l} + \varepsilon_t \quad (2)$$

where "gas_t" is the per gallon Gulf Coast price of regular gasoline and "wti_t" is the weekly Cushing, OK per gallon WTI spot price FOB (dollar price per barrel divided by 42), henceforth referred to as crude oil price, at time t. As defined above, z_t is an independent variable measuring the effect of the interaction between the structural break and crude oil price. $\delta_0 + \rho_0$ is the short-run effect–within the week after the change in the crude oil price. It is a priori expectation that $0 < \delta_0 + \rho_0 \leq 1$. $\delta_0 + \rho_0 < 1$ indicates sluggish adjustment or stickiness. $\delta_0 + \rho_0 = 1$ represents a complete pass-through in the short run.

Theoretically, the ARDL method proposed by Pesaran et al. (1997) has been a valuable tool for testing for the presence of long-run relationships between time-series. The advantage of the ARDL model is its ability to estimate both the long-term and short-term model parameters without requiring a pre-testing to determine the order of the cointegration of the variables; thus, avoiding the problems posed by non-stationary time series. This pre-testing is particularly problematic in the unit-root cointegration literature where the power of the unit-root test is typically very low, and where there is a switch in the distribution function of the test statistics as one or more roots of the right hand side variables process approach unity. Furthermore, the ARDL procedure is robust to small samples, allowing different optimal lags of variables.

However, Pereira and Maia-Filho (2013) argued that the bounds test is based on the assumption that variables are either I(0) or I(1). Therefore, it is prudent to determine the stationarity of the time series data. The most common testing procedures to test for stationarity of time series data are *Kwiatkowski-Phillips-Schmidt-Shin* and *Phillips-Perron.*

As to the empirical estimation, Enders (2015) suggested that the process to estimate the coefficients for equation (2) is to utilize the Akaike information criterion to select the largest values of *n, m* and s, deemed feasible; CUSUM Test is used to test for model stability. Breusch-Godfrey Serial Correlation Lagrange (LM) Multiplier Test is then used as a diagnostic to test the hypothesis that the residuals are $\{\varepsilon_\tau\}$ white noise.

As articulated by Pereira and Maia-Filho (2013), given the estimation results for equation (2), the long- run effect or pass-through can be calculated as:

$$\Phi = \frac{\sum_{k=0}^{m} \delta_k + \sum_{l=0}^{s} \rho_l}{1 - \sum_{j=1}^{n} \beta_j} \quad (3)$$

As articulated by Berstein and Fuentes (2003), Φ should be positive and close to 1. $\Phi = 1$ implies a complete pass-through in the long run. If $\Phi < 1$ or $\Phi > 1$, it implies either stickiness (less than perfect pass-through) or overshooting.

It is of interest to study the long-run relationship between the crude oil price and the gasoline price in the U.S. market to learn more about the nature of the impact of and oil shock in this economy. To this end, this investigation follows Pereira and Maia-Filho (2013) to use the bounds testing approach (Pesaran, Shin, and Smith, 2001) for the following error correction representation of the Autoregressive Distributed Lag model:

$$\Delta gas_t = \varphi + \sum_{j=1}^{n} \eta_j \Delta gas_{t-j} + \sum_{k=0}^{m} \pi_k \Delta wti_{t-k} + \sum_{l=0}^{s} \omega_l \Delta z_{t-l} + \lambda_1 gas_{t-1} + \lambda_2 wti_{t-1} + \lambda_3 z_{t-1} + \varepsilon_t \qquad (4)$$

where Δ is difference operator and the null hypothesis of "*non-existing of the long-run relationship*" is stated as $\lambda_1 = \lambda_2 = \lambda_3 = 0$. The relevant *F*-statistic for the joint significance of the *λ's* is calculated and compared with the critical values tabulated by Pesaran, Shin, and Smith (2001). If the estimated *F-statistic* is greater than the upper bound critical value, the variables are cointegrated. If it is below the lower bound, the null hypothesis cannot be rejected, i.e., there is no support evidence for long-run relationship between crude oil price and the gasoline price.

DATA AND DESCRIPTIVE STATISTICS

As to how the geographic location affects the pass-through rate of crude oil prices in the U.S. market, Chesnes (2012) argued that much of the extant literature comes to seemingly contradictory conclusions about the existence of this phenomenon, though the differences may be due to different data sources, price series, aggregation over time and *across geographic areas*, as well as misspecified models. Numerically, Blair and Mixon (2012) reported that "Depending *upon the region*, a $ 1 per barrel change in crude oil prices results in a change in retail gasoline pump prices somewhere between 2.52 cents and 2.65 cents".

Clearly, in their above cited statements, Chesnes (2012) and Blair and Mixon (2012) suggested that geographic variations significantly influenced the empirical results. Moreover, even in the same metropolitan area, retail gasoline prices varied from one sector to another. To mitigate these geographic variations, this investigation uses weekly wholesale prices of regular gasoline from the Gulf Coast region denoted gas_t with West Texas Intermediate crude oil denoted by wt_t from January 2, 1998 through February 10, 2017 to estimate the autoregressive distributed lag model (2). The difference between the gasoline and crude oil prices is defined as their spread and is denoted by PR_t. Figure 1 illustrates the *Gulf Coast regular gasoline price, per gallon West Texas intermediate crude oil price and their spread.* All time series data are collected from the U.S. Energy Information Administration databases, available at http://www.eia.gov/petroleum/.

EMPIRICAL RESULTS

The empirical results for this investigation are reported as follows.

The Degree of Cointegration

The bounds test is based on the assumption that variables are either I(0) or I(1). The most common testing procedures to test for stationarity of time series data are *Kwiatkowski-Phillips-Schmidt-Shin* and *Phillips-Perron.* The results of *Kwiatkowski-Phillips-Schmidt-Shin* and Phillips-Perron test of the per gallon Gulf Coast price of regular gasoline, gas_t, and weekly Cushing, OK per gallon WTI spot price FOB, wti_t, are summarized in Exhibit 1. The unit root tests reveal the per gallon Gulf Coast price of regular gasoline gas_t is an I(1) and weekly Cushing, OK per gallon WTI spot price FOB wti_t is also an I(1). Pereira and Maia-Filho (2013) argued that it is appropriate to use the bounds test to check for cointegration.

Structural Break

The estimation results for Perron's (1997) endogenous unit root test function with the intercept, slope, and the trend dummy are summarized in Exhibit 2.

The estimation results reveal that the post-break intercept dummy variable, *DU*, is positive and the post-break slope dummy variable, *DT*, is negative and both are statistically significant at the 1 percent level. The break dummy, $D(T_b)$ is negative and is insignificant at any conventional level. The time trend, *t*, is positive and is significant at the 10 percent level. These results suggest that the spread follows a stationary trend process. Moreover, strength of the test statistic, $t(a = 1) = -7.25622$ confirms the structural break in the week containing January 28, 2011.

ARDL Model

As discussed in the methodology section and based on the Akaike information criterion, the estimation process indicates that the optimal values are *n* = 4, *m* = 3, and s = 0 as the reported values for AIC in Exhibit 4 suggests, the ARDL (4, 3, 0) model has the lowest AIC value, therefore, it will be used for this investigation. The estimation results and diagnostic statistics for the autoregressive model, ARDL (4, 3, 0), are summarized in the following Exhibits 3, 4 and Figure 2.

The left panel of Exhibit 4 reports the diagnostic test testing for the correlation in the residuals. The right panel of Exhibit 4 reveals the AIC-values of the four best estimated models.

Figure 2 illustrates the graph of the CUSUM Test and its band of the 5 percent significance over the sample period.

An analysis of the overall estimation results indicates that there exists no serial correlation and that the model exhibits strong predictive power, as evidenced by the strength of the Breusch-Godfrey Serial Correlation Lagrange Multiplier Test $F(2,982) = 0.674396$ with the p-value being 0.5097 which also fails to reject the null hypothesis that there is no serial correlation in the residuals. As Figure 2 illustrates, the CUSUM Test statistic falls entirely in the band of the 5 percent level of significance. This empirical finding indicates the stabilities of the estimated parameters of the model over the sample period. Overall the diagnostic analysis indicates that the estimated ARDL(4,3,0) model is very reliable.

As reported in Exhibit 3, the estimated sum of $\delta_0 + \rho_0$ is 0.871036 (0.858739

+ 0.012297 = 0.871036). Also, using equation (3), the following calculation indicates that the estimated long-run crude oil price pass-through in the U.S. economy is Φ = 1.133020953. Even though they did not differentiate between short- and long-run pass-through rates, Blair and Mixon (2012) reported that "Depending upon the region, a $ 1 per barrel change in crude oil prices results in a change in retail gasoline pump prices somewhere between 2.52 cents and 2.65 cents". A $ 1 increase per barrel is equal to $1/42 = 0.0238 or 2.38 cents per gallon. It should be noted that given that the estimated long-run pass-through is 1.133020953, if the price of the crude oil increases by 2.38 cents per gallon, the estimated model predicts that the gasoline price should increase by 2.38x1.13302095 or 2.70 cents in the Gulf Coast region.

$$\Phi = \frac{\sum_{k=0}^{m}\delta_k + \sum_{l=0}^{s}\rho_l}{1-\sum_{j=1}^{n}\beta_j} = \frac{0.1158590 + 0.0122970}{1 - 0.8868900} = \frac{0.1281560}{0.1131100} = 1.133020953$$

Finally, to test the null hypothesis of "*non-existing of the long-run relationship-* $H_0 : \lambda_1 = \lambda_2 = \lambda_3 = 0$", the calculated value of the relevant *F-statistic* being 12.79708 for the joint significance of the hypothesis is compared to the critical upper values bounds at the 1 percent level of significance. Comparing the value of the *F*-statistic of 12.79708 to the critical value of the upper bound I(1) = 5.00 indicates that the null hypothesis of "*non-existing of the long-run relationship*" in the U.S. energy sector should be rejected at the 1 percent level of significance, suggesting that there is a long term relationship between the per gallon Gulf Coast price of regular gasoline and the weekly Cushing, OK per gallon WTI spot price FOB.

DISCUSSIONS OF THE EMPIRICAL RESULTS

The endogenous search process for breaks in the relationship between the per gallon Gulf Coast price of regular gasoline and the weekly Cushing, OK per gallon WTI spot price FOB using Perron's (1997) endogenous unit root test function with the intercept, slope, and the trend dummy found that the relationship between these two prices experienced a break in the week containing January 28, 2011. To account for this structural break, this investigation introduced a dummy variable and assigned the value of 1 from the week containing January 28, 2011 onward and 0 elsewhere over the sample period. Econometrically, this introduction of the dummy variable precipitated the generation of the interaction term between the dummy variable and the weekly Cushing, OK per gallon WTI spot price FOB. Due to the high correlation between the two regressors, only the interaction term was included in the modelling process. An analysis of the overall estimation results indicates that there exists no serial correlation and that the model exhibits strong predictive power and also confirms that the estimated residuals are white noise.

The estimation results of the Autoregressive Distributed Lag model, ARDL(4,3,0), represented by equation (2) and the derived long-run weekly Cushing, OK per gallon WTI spot price FOB pass-through, reveal that the U.S. weekly crude oil price pass-through rate, $\delta_0 + \rho_0 = 0.871036$.

Based on the Akaike information criterion, the longest lag retained by the estimation process for the per gallon Gulf Coast price of regular gasoline is 4 ($_{gas-4}$) and for the weekly Cushing, OK per gallon WTI spot price is 3 ($_{wti-3}$). These findings suggest that the gasoline wholesalers in the U.S. considered their selling price four weeks back in determining their current selling price; while these suppliers took up to three weeks to respond to the shock in crude oil price completely. Regarding time lags, Fondel et al. (2015) reported that "…Following shorter lag specifications that are established in the literature results in an estimated pass-through time of 6 to 8 weeks". Based on the estimation resulted reported in exhibit 3, the calculated long-run pass-through rate in the U.S. gasoline market is $\Phi = 1.133020953$.

Finally, as to the long-term relationship between the per gallon Gulf Coast price of regular gasoline gas_t and the weekly Cushing, OK per gallon WTI spot price FOB, wti_t, this investigation examines this issue by testing the above stated null hypothesis $H_0 : \lambda_1 = \lambda_2 = \lambda_3 = 0$. The testing procedure indicated that this hypothesis of no long-term relationship should be rejected at the 1 percent level of significance, suggesting a long-run relationship between the per gallon Gulf Coast price of regular gasoline gas_t and the weekly Cushing, OK per gallon WTI spot price FOB, wti_t, in the Gulf Coast wholesale gasoline markets.

CONCLUDING REMARKS

Historically, since the industrial revolution, industrialized nations have had a relatively inelastic demand for petroleum used for energy and lubrication. Given this inelasticity of demand, prices are disproportionately determined by changes in supply and are acutely sensitive to supply disruptions. Although unconventional natural gas production had been growing since the early 1980s, hydraulic fracturing technology had not been perfected or scaled to the point where full commercial deployment was competitive without subsidy. Shale gas production relied on Section 29 production tax credits and on developers like Mitchell Energy charging a premium for gas resources.

Having successfully demonstrated multi-fracture horizontal well development techniques in the Barnett Shale, engineers developed the optimal combination of inputs – water, proppant, and chemical lubricants, to achieve economic volumes of natural gas production. In 1998, Mitchell Energy engineers applied an innovative drilling technique called 'slickwater fracturing' (or 'light sand fracking') that significantly brought hydraulic fracture treatment costs down. This is the milestone that pushed shale gas into full commercial competitiveness. Since that historical moment, U.S. production volumes of oil and gas have increased drastically, reducing U.S. crude oil imports significantly.

On the demand side, a mild recession in the early 2000's, the U.S. subprime mortgage crisis, followed by the European sovereign debt crisis caused economic recession around the globe, slowing down the demand for gasoline in the international market. These in turn depressed crude oil prices. These aforementioned events motivated this investigation to study the nature of crude oil price pass-through in the U.S. since the aforementioned historical date.

To achieve the above objective, this study utilizes an Autoregressive Distributed Lag model to empirically investigate the nature of crude oil price pass-through in the U.S. economy. Estimation results suggest that, based on the Akaike information criterion, the ARDL(4,3,0) model best fits the data. Estimation results of the ARDL(4,3,0) model reveal that the U.S. short-run crude oil price pass-through rate is $\delta_0 + \rho_0$ is 0.871036 indicating that when the weekly Cushing, OK per gallon WTI spot price increases by 1 cent, the per gallon Gulf Coast price of regular gasoline increases by 0.87 cent within a 1 week timeframe.

The empirical findings further suggest that gasoline wholesalers in the U.S. consider their selling price four weeks back in determining current selling price while suppliers take up to three weeks to completely respond to shocks in crude oil price. These findings are very similar to what Fondel et al. (2015) reported, suggesting that "…Following shorter lag specifications that are established in the literature results in an estimated pass-through time of 6 to 8 weeks".

The calculated long-run pass-through rate in the U.S. gasoline market is Φ = 1.133020953. This empirical estimation of the per gallon ***wholesale price*** of the Gulf Coast price of regular gasoline is consistent with what Blair and Mixon (2011) reported, if the numerical values are set in the comparable footing, which is that "Depending upon the region, a $1 per barrel change in crude oil prices results in a change in ***retail gasoline pump prices*** somewhere between 2.52 cents and 2.65 cents.

The testing procedure testing the null hypothesis $H_0 : \lambda_1 = \lambda_2 = \lambda_3 = 0$ indicated that this hypothesis should be rejected at the 1 percent level of significance, suggesting a long-run relationship between the per gallon Gulf Coast price of regular gasoline and the weekly Cushing, OK per gallon WTI spot price.

ENDNOTES

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Figure 1: **Gulf Coast regular gasoline price and per gallon West Texas intermediate crude oil price.**

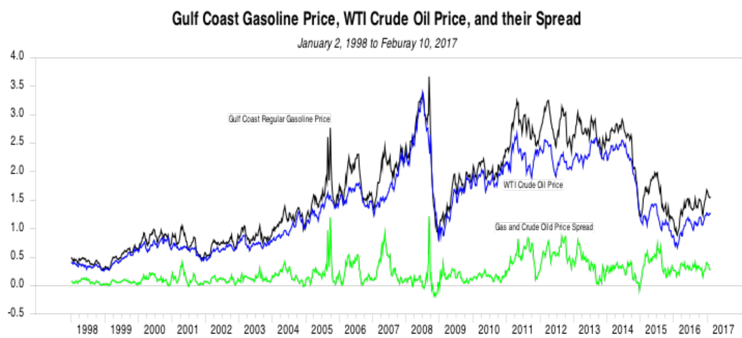


Exhibit 1: PP and KPSS Test Results, Oil and Gas Weekly Data, 1998:01:02 - 2017:2:10

	Phillips-Perron		***Kwiatkowski-Phillips-Schmidt-Shin***	
Series	**Level**	**Differencing**	**Level**	**Differencing**
gas_t	-2.251270^{n}	-27.3526^{y}	2.588851^{n}	0.069175^{y}
wti_t	-2.044708^{n}	-26.55829^{y}	2.383338^{n}	0.094595^{y}

Note: *"n"* and *"y" indicate whether the series is non- stationary and stationary at the 5 percent level*

Exhibit 2: Perron's Endogenous Unit Root Test, Oil and Gas Weekly Data, 1998:01:02 - 2017:02:10

$$PR_t = 0.01281 + 0.17152DU + 0.000003t - 0.00002DT - 0.06467D(T_b) + 0.85430PR_{t-1} + \upsilon_t$$
$$(2.11559) \quad (3.84954^{*}) \quad (1.94779^{***}) \quad (-3.40362^{*}) \quad (-0.86868) \quad (42.54787^{*})$$

Number of Augmented lags: k = 9 Break Date: Jan. 28, 2001 t(a = 1) = -7.25622*

Notes: Critical values for t-statistics in parentheses. Critical values based on n = 100 sample for the break date (Perron, 1997). "*" and "***" indicate significances at the 1 percent and the 10 percent levels.

Exhibit 3: Estimation Results for ARDL (4,3,0) Model and Bounds Test, Data, 1998:02:02 – 2017:02:10

ARDL (4, 3, 0): gas_t **is a dependent variable**			**Bounds Test:** gas_t **is a dependent variable**		
Variable	**Coefficient**	**t-statistic**	**Variable**	**Coefficient**	**t- statistic**
gas_{-1}	1.009544*	15.55879	Δgas_{-1}	0.123015*	3.824022
gas_{-2}	-0.276790*	-3.039077	Δgas_{-2}	-0.154424*	-4.835577
gas_{-3}	0.224987*	2.344522	Δgas_{-3}	0.070866*	2.591660
gas_{-4}	-0.070851**	-2.031875	Δwti	0.862317*	20.56447
wti_0	0.858739*	10.07446	Δwti_{-1}	-0.006457	-0.128558
wti_{-1}	-0.749145*	-6.949789	Δwti_{-2}	0.108878**	2.231963
wti_{-2}	0.114580	1.055102	wti_{-1}	0.116045*	6.822557
wti_{-3}	-0.108315	-1.379231	gas_{-1}	0.012368*	3.479883
z_0	0.012297**	2.094169	z_{-1}	-0.113297*	-7.137340
constant	0.015444*	2.659138	*constant*	0.015457*	2.773955

ARDL (4, 3, 0): R^2 = 0.992117 and $\bar{R}^2$ = 0.992045

F-value = 1,3759.83* and AIC = -2.380437

Bounds Test: R^2 = 0.352056 and $\bar{R}^2$ = 0.346130

F-value = 59.40559* and Bounds Test F = 12.79708*, k = 2

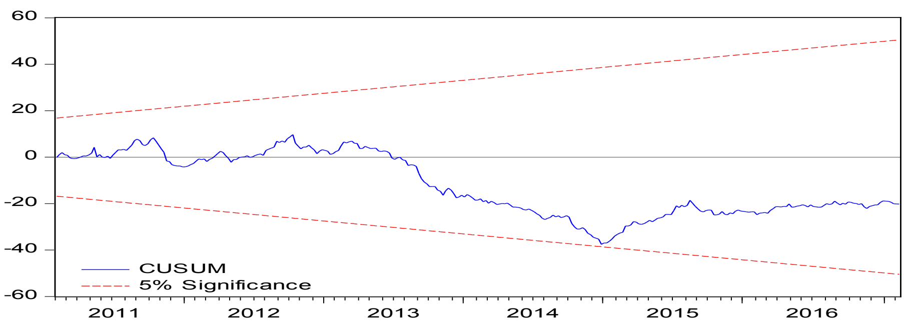
Note: "*" and "**" indicate 1 percent and 5 percent significance levels, respectively. Critical values for bounds tests at the10 percent: I(0) = 2.63, I(1) = 3.35; the 5 percent: I(0) = 3.10, I(1) =3.87; and the 1 percent: I(0) = 4.13, I(1) = 5.00.

Exhibit 4: Diagnostic Tests and Four Best Models According to AIC Criteria

Diagnostic Test	Model Selection Criteria	
	Four Best *Models*	*AIC*
Breusch-Godfrey Serial Correlation LM Test: H_0: There is no serial correlation in the residuals. $F_{(2,982)} = 0.674396$, p-value = 0.5097	***ARDL (4,3,0)***	***-2.372850***
	ARDL (5,1,0)	-2.372107
	ARDL (4,1,0)	-2.371969
	ARDL (10,5,0)	-2.371742

Note: data is from calculations by author.

Figure 2: CUSUM Test and its band of the 5 percent significance level.



Note: Graphic illustration of CUSUM Test to test for stability of model's estimated parameters.