Ex-ante Determinants of Volatility in the Crude Oil Market

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Abstract

This paper examines the causes and behavior of price volatility in the US crude oil market. Although crude oil prices are among the most volatile, they have received limited academic scrutiny heretofore. This study shows that (1) the crude oil market is characterized by volatility persistence, (2) a negative shock has more impact on future volatility than an equal positive shock, (3) crude oil volatility is lower at higher prices, (4) OPEC meeting announcements and the Petroleum Status Report releases cause increased volatility, and (5) there is a day-of-the-week pattern in this market. I develop and employ an improved procedure for testing and quantifying the hypothesized volatility determinants within GARCH type model.

Keywords: volatility, crude oil, GARCH, energy, determinant, shock

1. Introduction

This paper examines the causes and behavior of price volatility in the US crude oil market from January 1997 through December 2012. Crude oil is one of the most essential energy sources in the U.S., accounting for about 40% of the nation's energy consumption. Since OPEC's 1973 decision to regulate its oil price independently of large oil companies, crude oil prices have been subject to dramatic volatility. Oil prices increased from less than $11 per barrel in the beginning of 1999 to $38 per barrel in September 2000, decreased to $18 per barrel in January 2002 and went up to $77 per barrel in July 2006. The crude oil market experienced an unprecedented dramatic volatility in 2008 as crude oil prices reached an all-time high level of $145 per barrel in July and then fell sharply to $30 per barrel in December. This large oil price fluctuation tendency has continued in recent years. From less than $68 per barrel in May 2010, oil prices increased to $112 in April 2011 and then fell to $77 in October 2011.

Crude oil prices are more volatile than those in most financial markets. In 2013, the annualized standard deviation of the daily percentage change in prices was 21.92% for crude oil. By comparison, that number was only 6.07% for the US dollar-Euro exchange rate, 13.02% for the S&P 500, and 19.10% for the 10-year T-bond interest rates (Note 1). Figure 1 depicts crude oil prices and historical volatilities from January 1997 through December 2012 wherein historical volatilities are measured as the annualized rolling 30-day standard deviation of returns. As shown in these graphs, the crude oil market has undergone notable price fluctuations during the sample period and volatility tends to cluster over time.

The high volatility in crude oil prices is likely due to actual and anticipated fluctuations in supply and the short-term inelasticity of demand. Given that crude oil is one of the most essential energy sources, it is very difficult for most oil users to reduce their consumption within a short period of time following a price increase. On the other hand, there is considerable fluctuation in oil supply which depends on a variety of macroeconomic and political factors. For example, in 1997, when the world economy was already in a recession, the Organization of Petroleum Exporting Countries (OPEC), failing to predict the oil demand correctly, increased its production levels which resulted in a huge decrease in oil prices. In June-July 2008, a combination of supply uncertainties in oil producing countries and a falling dollar caused an unprecedented oil price spike. On the reverse, an appreciation of the dollar and signs of worldwide economic slowdown led to a sharp decrease in oil price in the end of 2008. In 2012, crude oil prices increased during the first quarter as concerns about possible international supply disruptions put an upward pressure on petroleum prices then decreased during the second quarter before turning sharply upward in the third quarter.

This high variability in crude oil prices makes it extremely difficult for consumers to forecast their costs and for producers to forecast their profits. The desire to protect market participants against such price fluctuations has led to

the creation of and active trading in futures, swaps and options where the market value of the latter depends on volatility.

Although it is difficult to forecast the direction of future price changes from past price behavior, the absolute magnitude of price changes, i.e. volatility, has been proven much more predictable in most financial markets. It is generally found that highly volatile markets tend to be followed by volatile markets whereas stable markets tend to be followed by stable markets. The vast majority of the research on market volatility has focused on the volatility of financial markets such as the stock, bond, interest rates and foreign exchange futures markets, etc. Despite the fact that crude oil prices, like any other energy prices, tend to be more volatile than most financial prices, research into the cause and behavior of volatility in the crude oil market is limited. For instance, in a well-known and comprehensive study of the volatility literature, Poon and Granger (2003) surveyed 93 articles examining volatility in all sorts of markets; only three of these included crude oil among the markets examined (Day and Lewis, 1993; Szakmary, Ors and Kim, 2003; and Martens and Zein, 2004).

An understanding of the causes and behavior of crude oil volatility is essential to measuring and managing the risk faced by energy producers and major consumers, such as airlines. Also the market value of risk management products such as options depends largely on volatility. However, most research on the crude oil market has focused on the behavior of oil prices rather than on volatility. The limited studies on crude oil volatility to date focus solely on volatility persistence, i.e., the relation between current and past volatility, in this market (see, for example, Wilson, Aggarwal and Inclan, 1996; Yang, Hwang and Huang, 2002; Pindyck, 2004; Kuper and Soest, 2006; Agnolucci, 2009; and Charles and Darne, 2014). Other possible determinants of crude oil volatility are neglected in the literature. This paper attempts to fill this gap in our understanding by simultaneously testing and quantifying several hypothesized ex-ante determinants of crude oil volatility. These determinants consist of volatility persistence, volatility asymmetry, oil price levels, announcement, and seasonality effects.

This study's most important results and contributions to the literature include the following. One, crude oil volatility is asymmetric in that an unexpected decrease in price increases predicted volatility more than an unexpected increase in price of similar magnitude. Two, crude oil volatility tends to be high when oil prices are historically low and low when prices are historically high. Three, crude oil volatility tends to increase on days the OPEC meetings announcements are released. Four, crude oil volatility is significantly higher on Monday, implying that the crude oil market is impacted by news occurring during the weekend and on Wednesday, possibly because Wednesday is the release day of the Weekly Petroleum Status Report. Five, a model which fails to control for levels, announcement, and seasonality effects tends to overestimate the impact of an unexpected price decrease on predicted volatility.

The model developed and used in this study is a variant of the regime-switching GARCH type methodology outlined in Jones, Lamont and Lumsdaine (1998). This model, which separates volatility into a persistent part and a transitory part, allows us to implement a much cleaner study of the determinants of volatility than that used in several previous studies on other markets.

To the best of my knowledge, this paper is the first comprehensive study of the ex-ante determinants of volatility within a GARCH framework for the crude oil market.

The paper is organized as follows. Section 2 proposes and develops the hypotheses. The data is presented in Section 3. Section 4 analyzes the multiplicative GARCH type model to quantify the determinants of crude oil volatility. Section 5 presents the results and Section 6 concludes the paper.

2. Hypotheses

This study attempts to answer the following questions:

1). Is there volatility asymmetry in the crude oil market? That is, do equal positive and negative shocks have different impacts on future volatility? It is generally documented that asymmetric volatility exists in a number of financial markets. French and Roll (1986), French, Schwert and Stambaugh (1987), Campbell and Hentschel (1992), Glosten, Jagannathan and Runkle (1993), Veronesi (1999), Bekaert and Wu (2000) and Wu (2001) and others found that in the stock market, an unexpected decrease in price has a bigger impact on predicted volatility than an unexpected increase in price of equal magnitude. The asymmetric volatility in the stock market is generally attributed to either a leverage effect and/or a volatility feedback effect (Note 2). To a lesser extent, Brunner and Simon (1996) and Simon (1997) found similar evidence for the Treasury bond futures and options markets, and Wang and Yang (2009) for the foreign exchange markets.

While in the stock market negative shocks tend to have more impact on predicted volatility than equal positive shocks, the hypothesized reasons, i.e., leverage and/or volatility feedback effects, would not apply to the crude oil

market. There are reasons to expect that due to the elasticity of the supply and demand curves, a positive shock in the energy market could have more impact on predicted future volatility than an equivalent negative shock. The supply and demand curves for crude oil are likely to be more elastic at low prices than at higher prices. Given the hypothesized shape of the supply and demand curves, the same fluctuation in demand when prices are low should cause a smaller change in prices than when prices are high. Thus, a positive price shock which moves the market up the supply and demand curves is likely to presage higher future volatility than a negative shock moving the market down the curves.

2). Is there levels effect in crude oil volatility? High oil prices which indicate that the supply and demand curves become inelastic should cause an increase in volatility. However, as depicted in Figure 1, periods of high volatility tend to be associated with low prices and periods of low volatility tend to be associated with high prices. Therefore, the price levels effect on crude oil volatility is an empirical issue to be explored.
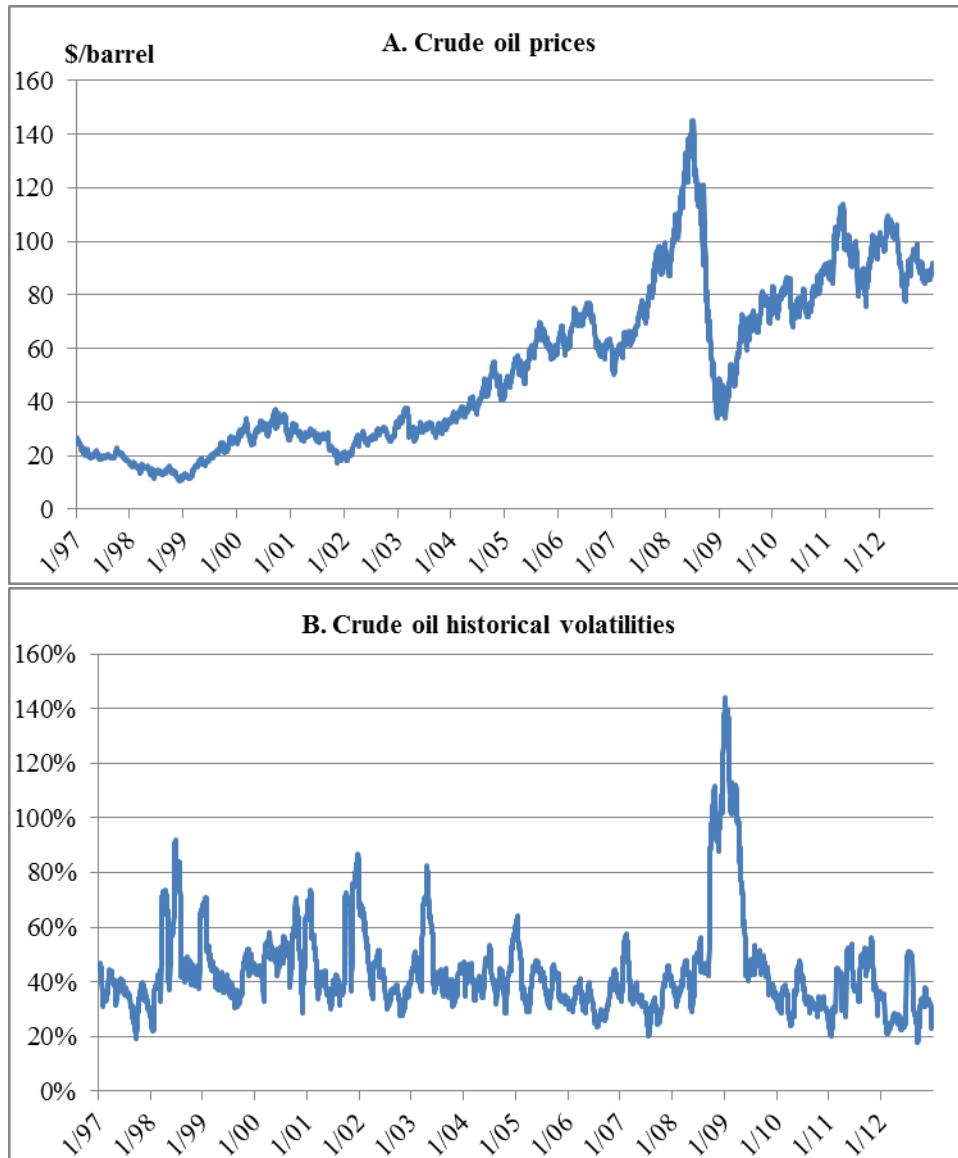

Figure 1. Crude oil prices and historical volatilities from January 1997 through December 2012

The vertical axes depict nearby futures prices and annualized rolling 30-day standard deviations of returns.

3). Do the OPEC meetings cause increased volatility in the crude oil market?

The Organization of Petroleum Exporting Countries (OPEC), founded in 1960, produces about 40 percent of the world's crude oil. OPEC nations control approximately 78% of known reserves and export about 55% of the oil traded internationally (Note 3). The Organization is required by its charter to hold a minimum of two conferences per

year, at which each member nation is to be represented. In addition to these regularly scheduled conferences, OPEC holds "extraordinary meetings" on an as-needed basis. During these meetings, the OPEC delegates often consider and ratify future production levels and therefore OPEC meetings are usually the subject of intense media attention.

Disagreement exists in the literature about the OPEC's influence on crude oil prices. Loderer (1985) and Gullen (1996) find that OPEC influenced crude oil prices in the eighties and nineties but not during the seventies and early eighties. Alhajji and Huettner (2000) reject the hypothesis that OPEC has a significant impact on crude oil prices. Conversely, Deaves and Krinsky (1992), Hyndman (2008) and Demirer and Kutan (2010) find that crude oil prices under-react to bullish outcomes of OPEC meetings and efficiently react to bearish outcomes. Despite the controversial evidence of the OPEC's influence on oil price levels, there are reasons to expect that OPEC news impact crude oil volatility. On days the OPEC decisions are coming to the market, market participants adjust prices according to new information and thus, the crude oil market should become more volatile. Since the OPEC meetings are generally not open to the press and most valuable news are not made known to the public until after the meetings (Note 4), this study hypothesizes that volatility will be higher on days following the OPEC meetings.

4). Are there seasonal effects in crude oil volatility?

4.1) Day-of-the-week pattern

Some academic studies find that the volatility of financial asset returns varies across days of the week. (Note 5) In some financial markets, the volatility from Friday close to Monday close is higher than that of a normal one-day period but not as high as that of a three-weekday period presumably because there is not much information coming out during the weekend. This study hypothesizes that crude oil volatility tends to be high on Monday (including weekend) since the crude oil market is likely to be affected by news occurring during the weekend, such as weather or geo-political events. This study also hypothesizes higher crude oil volatility on Wednesday, the release day of the Weekly Petroleum Status Report. This Report, which is compiled and issued by the U.S. Energy Information Administration, is widely considered one of the most important news in the crude oil market since it provides timely information on supply and inventory data of crude oil and principal petroleum products in the context of historical information and forecasts.

4.2) Time-of-the-year pattern

It has been documented that returns in some markets differ by month of the year (Note 6) but little attention has been given to a seasonal pattern in volatility. This paper investigates the possibility of a time-of-the-year volatility pattern in the crude oil market where part of the demand supposedly depends on weather conditions. For example, the demand for gasoline often increases during the summer driving season and similarly, the demand for heating oil may increase sharply in the winter season. Since gasoline and heating oil are two of the most important products distilled from crude oil (Note 7), an increase in product demand supposedly results in an increase in crude oil demand and if crude oil supply is essentially fixed in the short run, volatility would increase.

3. Data and Preliminary Analysis

These hypotheses are tested using daily closing prices of crude oil futures contracts traded on the New York Mercantile Exchange (NYMEX). Crude oil futures contracts, which began trading on the NYMEX on March 30, 1983, trade in units of 1,000 U.S. barrels. The sample period is January 1, 1997 to December 31, 2012 totaling 4,010 daily observations. Crude oil prices are from the Energy Information Administration (Note 8). Details of the OPEC meetings are collected from Dow Jones Factiva database.

Futures prices are used in place of spot prices for the following reasons. First, futures prices are the major prices in the crude oil market. The NYMEX crude oil futures contract is the world's most liquid forum for crude oil trading and is used as a principal international pricing benchmark. Crude oil futures prices are also the prices reported in newspapers. Second, the futures market for crude oil is liquid and centralized while spot markets are localized and illiquid. Third, futures prices are the prices normally used in most oil risk management contracts such as swaps and options.

To examine volatility in a GARCH type framework, I utilize daily log returns (Note 9) defined as $r_t=ln(P_t/P_{t-1})$ wherein P_t is the price of the futures contract on day t and P_{t-1} is the price of the same contract the previous day. As traders often cover their positions on the last trading day of a contract's life, trading volume and open interest decline and price volatility increases substantially. To avoid this "thin market" problem, in constructing the r_t series I replace the return of the nearest contract on its last trading day of each month with that of the second nearest contract.

Table 1. Summary statistics of crude oil returns

	Nearby		Second-month		Third-month	
	Returns	Absolute Returns	Returns	Absolute Returns	Returns	Absolute Returns
Mean (x10^2)	0.0249	1.8033	0.0243	1.6534	0.0283	1.5486
Maximum	0.1454	0.1654	0.1379	0.1572	0.1166	0.1216
Minimum	-0.1654	0.0000	-0.1572	0.0000	-0.1216	0.0000
Std Dev	0.0242	0.0162	0.0220	0.0145	0.0206	0.0136
Annualized Std Dev	0.3826	0.2561	0.3479	0.2293	0.3257	0.2150
Skewness	-0.2598	0.2283	-0.2512	0.2104	-0.2398	0.1972
Kurtosis	6.3969	12.9479	5.8826	11.9163	5.4104	10.0491
Rho (First order Autocorrelation coefficient)	-0.0114	0.0529[**]	-0.0279	0.0340[*]	0.0043	0.0492[*]

Notes: The third, fifth and seventh columns present summary statistics for absolute values of daily returns. ([**]) and ([*]) on Rho designate estimates significantly different from zero at the 0.01 and 0.05 levels, respectively.

Table 1 provides summary statistics for daily crude oil returns on nearby, second- and third-month contracts. The annualized standard deviation of the daily percentage change in nearby crude oil prices over the January 1997-December 2012 period is 38.26%, indicating a very high volatility in this market. There is evidence that volatility decreases with time to maturity of the futures contracts, from 38.26% for the nearby to 34.79% for the second-month and 32.57% for the third-month contracts.

Table 1 shows preliminary evidence of volatility persistence in that the first-order autocorrelation coefficients for absolute returns are positive and significant at the 0.01 level. For squared returns (not reported), the first-order autocorrelation coefficients are also significantly positive at the 0.001 level. Clearly, the crude oil market, like many others, is characterized by volatility persistence.

4. Model Specification and Analysis

In order to test and quantify the determinants of crude oil volatility as discussed in section 2, this study estimates a model in which the conditional variance follows a regime-switching GARCH type process:

$$r_t = \mu + \varphi_1 r_{t-1} + \varepsilon_t \tag{1}$$

where:

$$\varepsilon_t \sim N(0, \sigma_t^2) \text{ and } \sigma_t^2 = h_t \cdot s_t \tag{2}$$

$$h_t = Var(\zeta_t) = \omega + \alpha\zeta_{t-1}^2 + \beta h_{t-1} + \gamma\zeta_{t-1}^2 I_{t-1}, \text{ where } \zeta_t = \varepsilon_t / s_t^{.5} \tag{3}$$

$$s_t = \prod s_{i,t} \tag{4}$$

$$s_{1,t} = \lfloor AP_t / \overline{AP} \rfloor^\kappa \tag{4.a}$$

$$s_{2,t} = (1 + \delta_{-1} DA_{t-1})(1 + \delta_0 DA_t)(1 + \delta_1 DA_{t+1}) \tag{4.b}$$

$$s_{3,t} = \prod (1 + \lambda_i DW_{i,t}) \tag{4.c}$$

$$s_{4,t} = (1 + \theta_1 DSUM_{i,t})(1 + \theta_2 DWIN_{i,t}) \tag{4.d}$$

r_t is the log percentage change in futures price on day t, $I_{t-1}=1$ if $\zeta_{t-1} >0$ and 0 otherwise. The main interest of this study is in the ex-ante determinants of the variance of the surprise oil return, ε_t. This variance is modeled as a multiplicative function of an asymmetric GARCH function (equation 3), price levels (equation 4.a), announcement effects (equation 4.b), day-of-the-week pattern (equation 4.c) and seasonal effects (equation 4.d).

4.1 Volatility Persistence and Asymmetric Volatility

Equation 3 is the asymmetric GARCH model due to Glosten et al. (1993) often referred to as the GJR or TGARCH model. If volatility persistence is an attribute of the crude oil market, α and β should be significantly positive, implying that predicted volatility depends on both unexpected price changes and the previous day's forecast

volatility. Asymmetric volatility implies $\gamma \neq 0$ in equation (3); $\gamma > 0$ implies a positive shock increases conditional volatility more than an equivalent negative shock.

4.2 Levels, Announcement and Seasonality Effects

Equation 4, the transitory effects equation, estimates the impact of other determinants on volatility. Equation 4(a) tests the hypothesis that volatility is sensitive to price levels. AP_t is the inflation-adjusted price $= (P_t/CPI_T)100$ where P_t is the crude oil price on day t and CPI_T is the Consumer Price Index for that month. $\overline{AP}$ represents the average inflation-adjusted price over the sample period. $\kappa > 0$ implies a higher volatility at high price levels and $\kappa < 0$ implies a lower volatility at high price levels.

Equation 4(b) estimates the impact of OPEC meetings announcements on oil volatility. DA_t is 1 on OPEC meeting days and 0 otherwise. I also include DA_{t-1} and DA_{t+1} as dummies for the days before and after OPEC meeting days because (1) it is often reported in the media that market participants speculate on OPEC decisions and adjust prices prior to the meetings and (2) important OPEC meetings news are usually not released to the public until the following day. In equation 4(b), δ_i represents the estimated log percentage increase in volatility normally caused by OPEC meetings.

Equations 4(c) and 4(d) estimate the day-of-the-week and time-of-the-year patterns in crude oil volatility. $DW_{i,t}$ are zero-one dummies for Monday (which includes the weekend), Wednesday, Thursday and Friday with Tuesday being the left-out day. λ_i estimates the average percentage difference between volatility on day i and volatility on Tuesday. In other words, assuming that $s_{1,t}=s_{2,t}=s_{4,t}=1$, then the estimated variance on Tuesday is h_t. On Monday, the estimated variance is $h_t(1+\lambda_M)$. On Wednesday, the estimated variance is $h_t(1+\lambda_W)$ and so on for other days. If the crude oil market is impacted by news occurring over the weekend, Monday return (which is a three-day return including the weekend) should be more volatile than any normal weekday return and $\lambda_M > 0$. This study also hypothesizes that $\lambda_W > 0$ since Wednesday is the release day of the Weekly Petroleum Status Report.

$DSUM_{i,t}=1$ if the futures contract expires in the summer months (from May through August); $DWIN_{i,t}=1$ if the futures contract expires in the winter months (from November through February). θ_1 and/or $\theta_2 \neq 0$ imply a time-of-the-year pattern in crude oil volatility.

4.3 Comparison with Previous Models

The model in this study improves on that used in several previous studies which seek to simultaneously estimate both GARCH and other determinants of volatility. The introduction of a transitory volatility equation s_t into the specification enables us to implement a much cleaner study of the determinants of volatility than when announcement and/or day-of-the-week dummies are added to the variance equation. For instance, Hsieh (1989), Berument and Kiymaz (2001), Ederington and Lee (2001) and Lee (2002) use GARCH type models to examine day-of-the-week effects on volatility in other markets. In those studies, weekday dummies are in the h_t equation (equation 3) and the coefficient estimates reflect how conditional volatility changes across weekdays. Thus, using their model, there is no s_t equation (equation 4) and equation (3) becomes:

$$h_t = \omega + \alpha\varepsilon_{t-1}^2 + \beta h_{t-1} + \lambda_M DW_{M,t} + \lambda_W DW_{W,t} + \lambda_R DW_{R,t} + \lambda_F DW_{F,t}, \tag{5}$$

In equation 5, since weekday dummies are in the h_t equation, the dummy for any day of the week impacts volatilities on all days of the week through the h_{t-1} term on the right hand side of the equation. Suppose, for instance, that day t is Monday. $\partial h_t/\partial DW_{M,t} = \lambda_M$. Now consider the impact of the Monday dummy on volatility on Tuesday (day $t+1$). Since

$$h_{t+1} = \omega + \alpha\varepsilon_t^2 + \beta h_t + \lambda_M DW_{M,t+1} + \lambda_W DW_{W,t+1} + \lambda_R DW_{R,t+1} + \lambda_F DW_{F,t+1}, \tag{5}$$

$$\partial h_{t+1}/\partial DW_{M,t} = (\partial h_{t+1}/\partial h_t)(\partial h_t/\partial DW_{M,t}) = \beta\lambda_M. \tag{5'}$$

Likewise, the Monday dummy impact on the Wednesday's volatility is $\partial h_{t+2}/\partial DW_{M,t} = \beta^2\lambda_M$. Therefore, when weekday dummies are in the h_t equation, as in equation (5), λ_M does not measure how much higher volatility is on Monday than on the omitted day (Tuesday). Indeed, depending on the coefficient pattern, day X which has the highest λ_X coefficient may not be the day with the highest volatility.

In contrast, a specification which separates the variance of returns into a persistent part, equation (3), and a non-persistent part, equation (4), allows me to estimate a model in which any weekday dummy impacts that day's volatility only. For example, λ_M measures how much higher (or lower) in percentage terms the volatility is on Monday than on the omitted day (Tuesday) and λ_W measures how much higher (or lower) the volatility is on Wednesday and so on.

To estimate the announcement impacts on volatility, several previous studies, for example, Hsieh (1989), Berument and Kiymaz (2001), Ederington and Lee (2001), De Goeij and Marquering (2006), Schmidbauer and Rösch (2012), add an announcement dummy to the h_t equation and do not include the s_t equation. Thus, the variance equation becomes:

$$h_t = \omega + \alpha\varepsilon_{t-1}^2 + \beta h_{t-1} + \delta_0 DA_t, \qquad (6)$$

In equation (6), an unscheduled shock on day $t-1$ impacts volatility on day t through the term $\alpha\varepsilon_{t-1}^2$. However, since an announcement impact is forced to persist on the subsequent days $(\partial h_t/\partial DA_t = \delta_0,\ \partial h_{t+1}/\partial DA_t = (\partial h_{t+1}/\partial h_t)(\partial h_t/\partial DA_t) = \beta\delta_0,\ \partial h_{t+2}/\partial DA_t = \beta^2\delta_0$ and so on), the impact of a shock due to scheduled announcement on day $t-1$ on volatility on day t includes not only $\alpha\varepsilon_{t-1}^2$ but also $\beta\delta_0$. Consequently, models like equation (6) impose much higher persistence for shocks due to scheduled announcements than for equivalent shocks due to unscheduled announcements. In contrast, in this study's model, the impact of a shock due to scheduled announcement does not persist on the following days $(\partial \sigma_t^2/\partial DA_t = \delta_0$ and $\partial \sigma_{t+1}^2/\partial DA_t = 0)$ and therefore, the estimated impact of day $t-1$'s shock on subsequent day t's volatility is the same for scheduled and unscheduled announcements.

5. Results

Estimates of the specification (1-4) for nearby futures returns are presented in the third column of Table 2.

Table 2. The multiplicative GARCH-type model of volatility determinants

	GJR model	Full model		
		Nearby futures	Second-month futures	Third-month futures
ω	0.1847***	0.2114***	0.2639***	0.2361***
	(0.0387)	(0.0629)	(0.0791)	(0.0719)
α	0.0829***	0.0586***	0.0700***	0.0656***
	(0.0089)	(0.0123)	(0.0136)	(0.0129)
β	0.9066***	0.8974***	0.8681***	0.8636***
	(0.0111)	(0.0220)	(0.0296)	(0.0306)
γ	-0.0413***	-0.0179*	-0.0318*	-0.0182
	(0.0107)	(0.0089)	(0.0137)	(0.0148)
Level		-0.5354***	-0.3960***	-0.3095**
		(0.1134)	(0.1035)	(0.1040)
OPEC meetings		0.0605	0.1132	0.1251
		(0.2014)	(0.2145)	(0.2143)
OPEC meetings (+1)		0.5447*	0.7101*	0.6772*
		(0.2619)	(0.2858)	(0.3023)
OPEC meetings (-1)		0.4663	0.4471	0.4513
		(0.2919)	(0.2930)	(0.2845)
Monday		0.4040***	0.3902***	0.3293***
		(0.0936)	(0.0968)	(0.0981)
Wednesday		0.3260***	0.3282**	0.3169**
		(0.0902)	(0.0982)	(0.0964)
Thursday		0.0474	0.1084	0.1042
		(0.0774)	(0.0899)	(0.0893)
Friday		-0.0525	0.0370	0.0555
		(0.0681)	(0.0815)	(0.0831)
Summer		-0.0467	-0.1226	-0.1148

	(0.0885)	(0.0816)	(0.0815)
Winter	0.0629	0.0684	0.1259
	(0.0931)	(0.0933)	(0.0979)
Log-likelihood	-6716.549	-6687.190	-6423.765	-6219.350

Notes: Standard errors are shown in parentheses. (***), (**), (*) designate estimates significantly different from zero at the 0.001, 0.01 and 0.05 levels, respectively.

5.1 Volatility Persistence and Asymmetric Volatility

As documented in other studies, there is evidence of volatility persistence in the crude oil market. The estimates of α and β are positive and significant at the 0.001 level, implying that predicted volatility depends on both previous shocks and previous volatilities. Hence, in the crude oil market, highly volatile periods tend to be followed by volatile periods in the future and this finding is robust when I control for levels, announcement and seasonality effects. There is also evidence of asymmetric volatility in the crude oil market. The estimated γ is significantly negative, indicating volatility increases considerably more following a sudden decline in oil prices than following an equal sudden increase in prices.
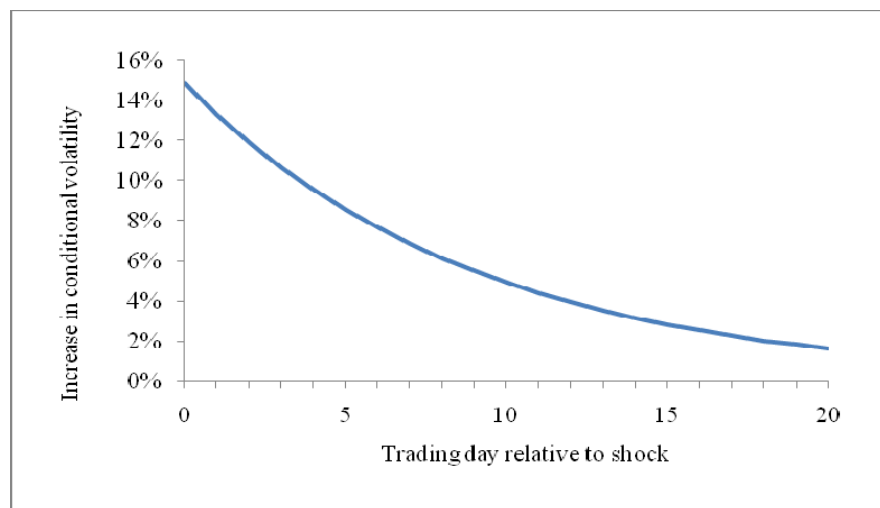

Figure 2. The change in conditional volatility following an oil return shock

Figure 2 presents the impact of a two-standard deviation oil return shock on subsequent predicted volatilities. Suppose the conditional variance, $h_{t-1}=Var(v_{t-1})$ is at its steady-state level and suppose there is a shock such that $v_{t-1}^2 = 4Var(v_{t-1})$. Figure 2 demonstrates the percentage difference in expected volatility on day $t+x$ and on day $t-1$, assuming $E(v_{t+x}^2) = Var(v_{t+x})$ for $x > -1$ and that negative and positive return shocks are equally likely. For example, the conditional volatility is about 14% higher the day after the shock and 7% a week later.

The second column of Table 2 presents estimates of a GJR model without levels, announcement and seasonality effects. In other words, I estimate a model consisting of equations (1-3) assuming that s_t=1. A comparison of the estimates from the GJR model (in the second column) and those from the full model (in the third column) indicates that other ex-ante determinants are important when modeling volatility in the crude oil market even after volatility persistence and asymmetry are controlled for. The likelihood ratio test statistics is 58.72 with 10 degrees of freedom and therefore, the null hypothesis of no levels, announcement and seasonality effects is rejected at the 0.001 level. The estimate of α is significantly higher from the GJR model than from the full model while the estimates of $(\alpha+\gamma)$ are not significantly different from each other.

Figure 3 plots different impacts of equal positive and negative shocks on predicted volatility according to the estimates from the GJR and the full models. Again, suppose the conditional variance, $h_{t-1}=Var(v_{t-1})$ is at its steady-state level. The conditional variance for day t falls 8% if there was no price change on day $t-1$ and rises about 17.50% if the price increased 15%. However, if the price fell 15% on day $t-1$, the conditional variance for day t increases 43.06% in the GJR model and only 28.52% in the full model. Apparently, failing to control for levels,

announcement and seasonality effects leads to an overestimation of a negative oil shock impact on predicted volatility and the overestimation is approximately 41.13% (Note 10).
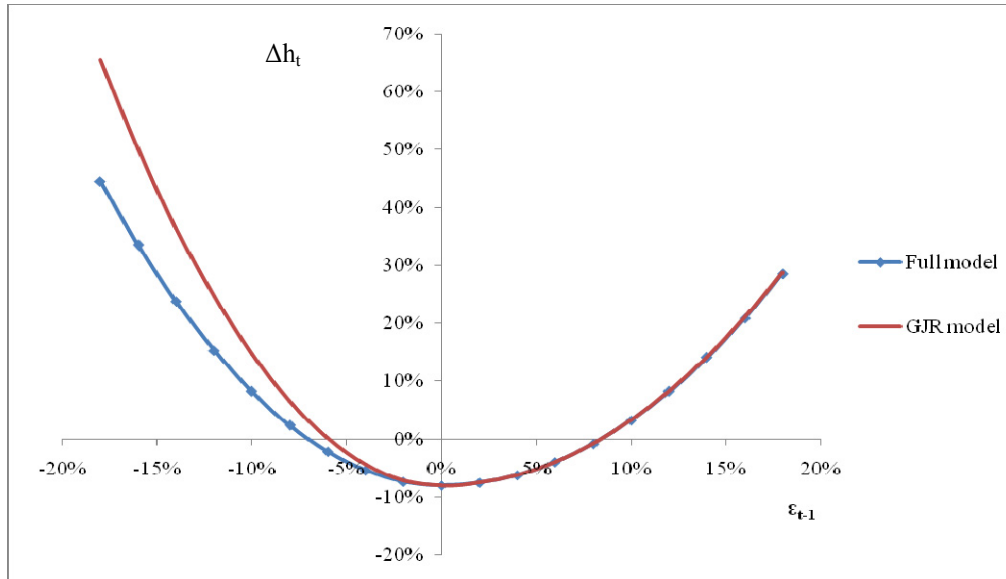

Figure 3. Estimated News Impact Curves

This figure depicts how equal positive and negative return shocks at time t-1 impact predicted volatility in the crude oil market according to the estimates of the GJR model and those of the full model. These curves demonstrate how a return shock in time t-1, ε_{t-1}, is incorporated into volatility estimates (as measured by Δh_t, the percentage change in conditional variance from day t-1 to day t). h_{t-1} is assumed to be equal the unconditional variance.

To test whether the omission of levels, announcement or day-of-the-week effects is responsible for this overestimation, I estimate specifications consisting of equations (1-3) and either equation 4(a), 4(b) or 4(c). Results (not reported) indicate that the overestimation caused by a model failing to control for announcement and day-of-the-week effects is just 2.73% while the overestimation caused by a model failing to control for levels effects and either announcement or day-of-the-week effects is approximately 40%. Apparently, failing to control for levels effects is the main cause of the overestimation of a negative oil shock impact on predicted volatility.

5.2 Levels Effect

Somewhat consistent with the evidence that a positive oil shock has less impact on predicted volatility than an equivalent negative shock, the estimate for κ, the levels effect, is significantly negative, indicating high crude oil volatility when prices are low and low when prices are high. As shown in Figure 1, crude oil volatilities were high during the periods 02-07/1998, 11/1998-01/1999, 10/2000-01/2001, 10-12/2001, 10-11/2008, 09-10/2011, and 05-06/2012 which were accompanied by low prices. In contrast, the periods 02-07/2007, 06-08/2008, 04-05/2011, and 03-04/2012 are characterized by both high prices and low volatilities. December 2008 to March 2009 was an interesting period in the crude oil market which was featured by both extremely high volatilities and historically low prices.

This finding for the crude oil market is opposite to the evidence in the interest rates market wherein volatility is high (low) when interest rates are high (low). This contrast is possibly explained by different volatility measures being used. Most studies on interest rates market use volatility of the interest rate change while this study uses volatility of the log percentage change in oil price.

5.3 OPEC Meetings

As indicated by the parameter estimates in Table 2, decisions made at the OPEC meetings tend to contain important information for the crude oil market. On the day after OPEC meetings, the standard deviation of crude oil returns increases by 24.29% (Note 11). This concurs with the observation that news from OPEC meetings are not made known to the market until the following day. Contrary to media assertions that market participants adjust prices in speculation of OPEC decisions, there is apparently no significant evidence that crude oil volatility increases on or before OPEC meeting days.

5.4 Seasonality

5.4.1 Day-of-the-week Pattern

The coefficients in Table 2 measure the difference between average volatility on each weekday and on Tuesday (since Tuesday is the left-out dummy). Contrary to the findings for some other markets (Note 12), there is no significant evidence of higher crude oil volatility on Friday. Apparently while Friday is the release day of important economics news for most financial markets, this is not the case for the crude oil market.

As expected, Monday returns (including weekend) tend to be more volatile than any normal weekday returns. The standard deviation of Friday-close-to-Monday-close return is 18.49% (Note 13) higher than that of Tuesday and the difference between Monday and Tuesday volatilities is significant at the 0.001 level.

Crude oil volatility tends to increase on Wednesday as the standard deviation of Wednesday return is 15.15% higher than that of Tuesday return and the difference is significant at the 0.001 level. The higher Wednesday volatility is likely caused by the release of the Weekly Petroleum Status Report which is widely considered one of the most important announcements in the petroleum market. This report provides timely information about current supply and demand conditions in the petroleum market and is therefore followed closely by market participants.

5.4.2 Time-of-the-year Pattern

Contrary to prior expectation, there is no significant evidence of higher crude oil volatility during the summer driving season or the winter heating season. (Note 14) Apparently crude oil volatility is less likely to be determined by the fluctuation in demand for petroleum products.

To further explore a month-of-the-year pattern in crude oil volatility, I re-estimate specification (1-4) with equation 4(d) expanded to include 11 monthly dummies. Results from this expanded specification (Note 15) indicate that September and October are the two least volatile months in a year. As the summer driving season ends and the winter does not arrive, this is the period of low crude oil demand. This slowdown in demand is often coupled with an increase in supply as numerous oil producing countries increase production and shipping of oil before their ports ice over during the winter.

5.5 Determinants of Volatility across Terms to Maturity

The last two columns of Table 2 report estimation results of the specification (1-4) for second- and third-month futures returns. There is evidence of volatility persistence for these returns. However, there is no evidence of asymmetric volatility for third-month futures returns.

The impact of OPEC announcements on crude oil volatility is more pronounced for longer term-to-maturity contracts than for nearby contract. On the days following OPEC meetings, the standard deviation of nearby returns increases by 24.29% while the increases for second- and third-month are 30.77% and 29.51%, respectively. Since OPEC meetings announcements mostly contain information regarding crude oil production levels, this sort of information is likely to have more impact on longer term-to-maturity contract prices than on nearby contract price.

There also exists a day-of-the-week pattern in longer term volatilities. The increase in Monday volatility (including weekend) is less sizable for third-month returns than for nearby and second-month. Apparently, news occurring during the weekend such as weather or geo-political events tends to have more implication for crude oil prices in the short term than in the long term. In contrast, the increase in Wednesday volatility does not significantly differ across terms to maturity, implying that the Petroleum Status Report is viewed by the market as having similar impact on crude oil prices in the short run and in the long run.

6. Summary and Conclusions

The contribution this paper makes is to provide an empirical examination of the causes and behavior of price volatility in the crude oil market. Daily returns data from January 1997 through December 2012 are used to estimate a multiplicative GARCH type model. The crude oil market is characterized by volatility persistence where highly volatile periods are followed by highly volatile periods and stable periods are followed by stable ones. This paper finds that a negative crude oil shock has more impact on predicted volatility than an equivalent positive shock. A somewhat surprising result is the evidence of low crude oil volatility when prices are high and high when prices are low. The OPEC meetings cause increased crude oil volatility on days the meetings announcements are released. There is a day-of-the-week pattern in the crude oil market in that Monday return (including weekend) is more volatile than any normal weekday return. The high weekend/Monday volatility is mainly due to the accumulation of information over the weekend. Crude oil volatility tends to increase on Wednesday, the announcement day of the

Petroleum Status Report. In contrast to the findings for some financial markets, there is no evidence of higher Friday volatility in crude oil market.

This paper uses a regime-switching asymmetric GARCH type model which separates volatility into a persistent part and a non-persistent part. This model allows us to implement a much cleaner study of the ex-ante determinants on volatility than that used in some previous studies.

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Notes

Note 1. The data for the S&P 500, US dollar-Euro exchange rate, and the 10-year T-bond interest rates were collected from CRSP database and the Federal Reserve website (http://www.federalreserve.gov).

Note 2. Wu (2001) provides a survey on the determinants of asymmetric volatility in the stock market.

Note 3. What is OPEC? (OPEC, 2006)

Note 4. Platts (2002)

Note 5. The literature on day-of-the-week effect on volatility includes French and Roll (1986), Berument and Kiymaz (2001), Martens et al. (2009) for the stock market, Harvey and Huang (1991), Ederington and Lee (1993) for interest rates and the foreign exchange futures market and Jones et al. (1998) for the Treasury bond market.

Note 6. See, for instance, Keim (1983), Lakonishok and Smidt (1984) for the stock market and Jordan and Jordan (1991) for the corporate bond market

Note 7. A 42-U.S. gallon barrel of crude oil provides slightly more than 20 gallons of finished motor gasoline and 10 gallons of heating oil and diesel fuel.

Note 8. http://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=RCLC1&f=D

Note 9. The daily crude oil "returns" are used to measure price changes only. These "returns" are not investment returns since no money is actually invested.

Note 10. This is measured as $1-(E_{wo}/E_w)$ where E_{wo} represents the estimate of α from the GJR model where I do not control for seasonality, announcement and levels effects and E_w that from the full model where I do.

Note 11. This is calculated as: $(1+.5447)^{1/2}-1= 24.29\%$

Note 12. For example, Harvey and Huang (1991) reported higher volatility in interest rate and foreign exchange futures market on Friday. Ederington and Lee (1993) further supported these results. Jones et al. (1998) and Berument and Kiymaz (2001) found similar evidence for the bond and stock markets.

Note 13. This is calculated as: $(1+.3663)^{1/2}-1= 16.88\%$

Note 14. I also estimate the specification (1-4) using gasoline and heating oil data during the sample period and find significant evidence that gasoline volatility increases during the summer months and heating oil volatility increases during the winter months.

Note 15. Results are available upon request.