DO SCHEDULED ANNOUNCEMENTS AFFECT MARKET UNCERTAINTY

IN ENERGY DERIVATIVE MARKETS?

by

MUNA SHARMA

(Under the Direction of Berna Karali)

ABSTRACT

We examine the impact of inventory and macroeconomic news releases on market uncertainty, as measured by volatility of futures returns and volatility implied by options prices, in crude oil, heating oil, and natural gas derivative markets. We document strong inventory announcements effects in all three markets, with an increase in return volatility and a drop in implied volatility on the day of inventory report releases. There is little evidence of macroeconomic announcements impacting these energy markets. We also find existence of the day-of-the-week pattern in crude oil options and natural gas futures markets.

INDEX WORDS: energy derivatives, futures, implied volatility, options, return volatility, scheduled announcements

DO SCHEDULED ANNOUNCEMENTS AFFECT MARKET UNCERTAINTY IN ENERGY DERIVATIVE MARKETS?

by

MUNA SHARMA

B.S., Tribhuvan University, Nepal, 2010

M.S., Tribhuvan University, Nepal, 2013

A Thesis Submitted to the Graduate Faculty of the University of Georgia in Partial Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE

ATHENS, GEORGIA

2017

DO SCHEDULED ANNOUNCEMENTS AFFECT MARKET UNCERTAINTY

IN ENERGY DERIVATIVE MARKETS?

by

MUNA SHARMA

Major Professor: Berna Karali
Committee: Jeffrey H. Dorfman
Gregory J. Colson

Electronic Version Approved:

Suzanne Barbour
Dean of the Graduate School
The University of Georgia
August 2017

DEDICATION

I would like to dedicate this thesis to my parents, brothers and sisters, daughter, and beloved husband.

ACKNOWLEDGEMENTS

I would like to express my deep gratitude to my advisor, Dr. Berna Karali, for her guidance, unconditional support and mentoring. I would also like to thank my committee members, Dr. Jeffrey H. Dorfman and Dr. Gregory J. Colson for their suggestions and constructive inputs during the preparation of this thesis.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Over the last decade, volatility has become an important issue in the energy market. Since the summer of 2008, energy futures prices (for example, crude oil and, heating oil) have been markedly volatile; with an extraordinary swing in price from the record level high ($ 148/barrel) to less than half the value ($ 35/barrel) just within few months' interval (Karali and Ramirez, 2014). Energy price volatility has become important to study because of its several economic implications. For instance, most of the energy price shocks were all followed by economic recessions, implying influential impact on the macro-economy (Ye, Karali, and Ramirez, 2014). The more volatile the crude oil prices, the more uncertainty it creates and therefore, leads to an unstable economy for both oil exporting and importing countries (Narayan and Narayan, 2007). Besides, energy price volatility has been shown to have significant spillover effect on agricultural markets. High energy prices have contributed to rising food prices because the price of energy inputs accounts over one-third of the cost of grain production (Hertel and Beckman, 2011). The energy sector, holding around seven percentage of Consumer Price Index (CPI), also directly affects the inflation rate (Narayan and Narayan, 2007).

What causes energy price volatility? This is the question of interest among market participants, researchers, and policy makers. One strand of literature views demand and supply factors as primary drivers of commodity price volatility (Pindyck, 2004; Sanders and Irwin, 2010, 2011; Kilian and Murphy, 2014) whereas another strand stands for speculative trading (Sanders, Boris and Manfredo, 2004; Tang and Xiong, 2012).

This study aims to investigate the impact of inventory and macroeconomic information releases on market participants' uncertainty regarding energy prices. Our measure of market uncertainty is implied volatility. Implied volatility is an unbiased estimate of expected volatility in future (Nikkinen, Sahlstrom, and Vahama, 2006), and one of the most important factors contributing in pricing options. Therefore, a thorough understanding of implied volatility is important to help option traders in selecting proper trading strategies. Several studies have shown that scheduled announcements resolve market uncertainty, characterized by a rise in implied volatility before announcements and a drop on the day of announcements (Ederington and Lee, 1996; Horan, Peterson, and Mahar, 2004; Isengildina et al., 2008). Therefore, market's reaction to new information is reflected in the change in implied volatility from the day before the announcement to the announcement day. Thus, predicting the change in implied volatility could help market participants in choosing sound hedging and investment decisions (Lee and Zyren, 2007). In addition, persistent change in implied volatility would signal higher uncertainty, exposing producers and consumers to risk, thus altering investments in fixed capitals (Pindyck, 2004).

Assuming fully efficient energy derivative markets, a number of event studies have been conducted around scheduled announcements. Market efficiency implies that prices instantly adjust to assimilate any new, relevant information. Regularly disseminated new information is therefore expected to affect price volatility in derivative markets through reconciling and adjusting past expectations. While volatility in energy futures prices around inventory and macroeconomic announcements have been a focus of extensive research, surprisingly less has been investigated in options market. This study fills the existing gap and contributes to the body of literature in several ways. Most of the studies measure returns volatility, which is an ex-post measure of volatility describing what actually happened in the market. Our study examines energy volatility by using both ex-ante (implied volatility) and ex-post (futures return volatility) measures. We investigate the responses in both futures return volatility and implied volatility on the release days of inventory reports and macroeconomic news for crude oil, heating oil, and natural gas. Incorporating all the three commodities' inventory reports in the analysis of energy market helps to determine possible cross-commodity effects. In addition, we analyze day-of-the-week pattern.

The U.S. Department of Energy's agency, Energy Information Administration (EIA) publishes weekly inventory reports on crude oil and key petroleum products, and natural gas. Inventory reports are essential to study because market participants regard these reports as an important piece of news influencing the energy market and as a result they trigger the price volatility (Linn and Zhu, 2004; Bu, 2014; Halova, Alexander, and Kucher, 2014). Storage plays a crucial role in stabilizing price of storable commodities through inter-temporal shift in supply. Any shift in storage level from equilibrium could move futures price, that is, increase in storage level is expected to put downward pressure on price and vice-versa (Ye and Karali, 2016).

Further, aggregate economic and business conditions are the subject of market concern. For instance, an increase in industrial production, which measures the pace of economic growth and business cycles, signals the period of expansion in which demand for goods and services from the industrial and commercial sectors are expected to increase putting upward pressure on energy prices (Karali and Ramirez, 2014). Similarly, increased number of jobs in industries also signals increased demand for goods and services from energy sector and thus, puts upward pressure on energy prices. Consequently, employment and industrial production are key indicators of the economy, and hence we expect that their report releases do affect the volatility of energy prices.

Our examination uncovers several interesting findings. We find an increase in return volatility and a decline in implied volatility on the day of important scheduled announcements. These results are consistent with the findings in previous studies (Ederington and Lee, 1996; Nikkinen and Sahlstrom, 2004). Specifically, our study demonstrates significant responses in volatilities of crude oil, heating oil, and natural gas to the release of their own inventory reports. We also find that crude and heating oil volatilities reacted significantly to the natural gas inventory report release. However, the release of petroleum status report has no explanatory power on natural gas. Notably, no significant responses in return volatility and implied volatility are found for the macroeconomic announcements in case of crude and heating oil. However, both volatility series of natural gas significantly reacted to the release of employment reports. Moreover, there is strong evidence for the day-of-the-week pattern in options market for crude oil and futures market for natural gas.

The remainder of the thesis is organized as follows. Chapter 2 reviews the related studies in the literature. Chapter 3 presents the data source and summary statistics. Chapter 4 describes the test used for preliminary analysis and the empirical models. Chapter 5 summarizes the results. Finally, we provide concluding remarks along with the implications in Chapter 6.

CHAPTER 2

LITERATURE REVIEW

It is well established in the literature that energy prices exhibit high volatility (Fleming and Ostdiek 1999; Regnier, 2007). Various researchers have widely studied the determinants of energy prices and their volatility. Pindyck (2001), for instance, reports demand and supply factors as the basic energy price determinants. On the demand side, weather plays an important role in the energy market (Karali and Ramirez, 2014). While demand for energy increases in winter due to demand for space heating, demand for natural gas also increases in summer when the days are hotter than normal as an input for space cooling. This uncertainty in demand creates uncertainty in prices and thereby increases volatility (Karali and Ramirez, 2014). Suenaga, Smith, and Williams (2008) model seasonality in the volatility of natural gas futures prices and show that volatility is higher for winter delivery contracts compared to other contracts. However, a study conducted by Mu (2007) provides no evidence for the higher volatility of natural gas during winter. Suenaga and Smith (2011) find in their study that heating oil prices are more volatile from December through March.

Demand for and supply of energy commodities also depend on macroeconomic variables such as real economic activity and interest rates (Karali and Power, 2013; Karali and Ramirez, 2014). Therefore, releases of reports related to macroeconomic indicators are expected to move the energy market. However, the empirical evidence on the influence of macroeconomic announcements on energy prices is mixed. Roache and Rossi (2010) explore the relationship between 13 macroeconomic news and commodity prices. They confirm that commodity prices (including precious metals, oil/gas, and agricultural produce) have been relatively insensitive to macroeconomic announcements as compared to financial assets. Kilian and Vega (2011) study the reaction of daily futures return in oil and gasoline to the release of 30 different U.S. macroeconomic announcements and confirm the total absence of feedback from announcements to prices. Chatrath, Miao, and Ramchander (2012) extended on the Kilian and Vega's study and fail to detect an important role of macroeconomic news on price fluctuations after controlling for inventory shocks. Chan and Gray (2017) examine the response of price movement in the energy market to the release and information content of scheduled macroeconomic announcement using both Symmetric and Asymmetric Generalized Autoregressive Conditional Heteroscedasticity (GARCH) - Jump models and find little evidence for the existence of a significant linkage between scheduled announcements and energy price jump dynamics. However, natural gas price jump dynamics are significantly affected by unemployment reports.

Contrast to other studies, Elder, Miao, and Ramchander (2013) employ high-frequency intraday data and document the strong linkage between crude oil price jumps over five-minute intervals and the release of economic information. Similarly, Basistha and Kurov (2015) find significant response in energy prices to unexpected change in federal fund rates. Belgacem et al. (2015) study the impact of macroeconomic announcements on daily crude oil return volatility using a GARCH framework. While they find significant impact of unemployment reports along with few other reports, they find no effect of industrial production reports. To expand on the existing dispute on the role of macroeconomic news on energy price volatility, we include two major announcements, namely Employment Situation and Industrial Production and Capacity Utilization in our model and study the volatility behavior on the report release days.

Inventory level is also an important factor affecting volatility. Storage stabilizes demand and supply shocks, mostly at the time of highly variable demand. The theory of storage implies smaller price response to demand and supply shocks at high inventory levels and high price volatility at low inventory levels (Karali and Ramirez, 2014). As energy commodities are storable, their price depends on the demand for pre-determined inventories (Alquist and Kilian, 2010). This implies that energy prices may jump in response to any news about their future supply or demand.

Inventory reports have been extensively used in the literature to examine their impact on futures returns and volatility in energy markets. Chang, Daouk, and Wang (2009) examine the intraday crude oil futures returns by using analysts' forecast from Bloomberg. They find significant response of returns to unexpected change in inventory levels immediately after the release of inventory report. Demirer and Kutan (2010) study the behavior of crude oil daily futures and spot price around Strategic Petroleum Reserve (SPR) announcement by categorizing the announcement into two categories: SPR increase and SPR decrease. They find that market reacts with an upward price adjustment following SPR increases, and with a downward price adjustment following SPR decreases.

Bu (2014) investigates the impact of EIA's crude oil inventory announcement on crude oil price movement and volatility using a GARCH model. The results show that inventory information shocks negatively affect the crude oil returns but no significant effect is observed on the return variance. Linn and Zhu (2004) find a large increase in intraday volatility of natural gas futures returns after the release of natural gas storage reports and the effect dissipates after 30 minutes. Similarly, Mu (2007) finds the higher volatility of natural gas futures return on the days of natural gas report releases using a GARCH model. Halova, Alexander, and Kucher (2014) show that volatility of natural gas futures return increases with the unexpected change in natural gas inventories. In addition, they find that volatility of both crude oil, and heating oil significantly reacts to the inventory surprises in crude oil and natural gas. To capture the effect of inventories, we include inventory report release days in our model and make comparisons between announcements vs. non-announcement days. We expect futures return volatility to increase and implied volatility to decrease on the release days of inventory reports.

Day-of-the-week effect is also another factor that needs to be considered. Auer (2014), by employing a dummy-augmented GARCH model, finds that volatility of crude oil futures is significantly higher on Mondays compared to all other weekdays. Murry and Zhu (2004) and Mu (2007) also show that volatility of natural gas is higher on Mondays than any other days. In our study, we investigate these effects using *F*-tests and *t*-tests for comparisons across announcement vs. non-announcement days and expect higher volatilities on Mondays and lower volatilities on Fridays.

We extend on this body of literature by measuring the response of energy prices in both futures and options market. Instead of only studying return volatility, our study focuses on implied volatility, a forward-looking measure of uncertainty. Miao et al. (2017) is the first study looking at the impact of inventory announcements on crude oil futures and options prices. They model futures and options returns with the surprise content of inventory reports through a simple regression and find a significant increase in returns with the negative inventory surprise and a decrease with the positive surprise. In contrast, we model futures return volatility and changes in implied volatility in response to inventory and macroeconomic announcements within a GARCH framework. Using volatility series is advantageous because volatilities are more predictable than return series.

CHAPTER 3

DATA

3.1 Futures Returns

For the empirical analysis, we consider three energy futures contracts that are traded on the New York Mercantile Exchange (NYMEX): crude oil, heating oil, and natural gas. Daily settlement prices of light sweet crude oil (WTI), heating oil, and natural gas (Henry Hub) futures contracts are obtained from the Commodity Research Bureau (CRB). WTI contracts are traded until the third business day prior to the 25th calendar day of the month preceding the delivery month. Each contract stands for 1,000 barrels and the price is quoted in U.S. dollars and cents per barrel. Heating oil contracts cease trading on the last business day of the month preceding the delivery month. Contract size for heating oil is 42,000 gallons and the price is quoted in U.S. dollars and cents per gallon. Natural gas futures contracts terminate trading three business days prior to the first day of the delivery month. Standard contract size for natural gas is 10,000 million British thermal units (mmBtu) and is quoted in U.S. dollars and cents per mmBtu.

Trading hours of these three energy futures contracts are 9:00 am -2:30 pm EST. Each commodity has multiple futures contracts trading at the same time with contracts maturities in every month of a year. Nearby price series for all three commodities are constructed by rolling over the first nearby contract on the first business day of the month prior to expiration month. Specific futures contracts used in each calendar months are shown in Table 1. For the trading days in July, for instance, nearby series consists of settlement prices of September futures contracts. Our sample spans from July 1, 1998 to June 5, 2013.

Daily futures returns, R_t, and return volatility[1], RV_t, are calculated as:

$$R_t = 100 \text{ x } ln\,(P_t/P_{t-1}), \tag{1}$$

$$RV_t = |R_t - \bar{R}|, t = 1, 2 \ldots, T \tag{2}$$

where P_t is the daily settlement price of the futures contract on day t and $\bar{R}$ is the average return over the sample period. Figure 1 plots the settlement price of all three commodities futures contract. Figure 2 shows the volatility clustering in return volatility series, meaning large changes are followed by large changes and smaller changes are followed by smaller ones.

3.2 Implied Volatility

Our measure of markets' uncertainty is implied volatility calculated by the CRB. Implied volatility is the market's estimate of how volatile the underlying futures will be over the life of an option contract and predicts realized volatility better than the historical volatility (Szakmary et al., 2003). The implied volatility is calculated as the average of implied standard deviation of the two nearest-the-money call options and that of two nearest-the-money put options. For calls and puts, each of the implied volatility is the value of σ_t obtained by substituting all other parameters into the Black's (1976) option pricing model:

$$C_t = e_t^{-r}\,[F_t\phi(d_{1t}) - K\phi(d_{2t})], \tag{3}$$

$$P_t = e_t^{-r}T\,[K\phi\,(-d_{2t}) - F_t\phi(-d_{1t})], \tag{4}$$

$$d_{1t} = [ln(F/K) + 0.5\sigma_t^2\,T_t]\,/\,\sigma_t\sqrt{T_t}\,, \tag{5}$$

$$d_{2t} = d_{1t} - \sigma_t\sqrt{T_t}, \tag{6}$$

where C_t is the call price, P_t is the put price, K is the exercise price, r_t is the risk-free interest rate, T_t is time to expiration of the option contract, and ϕ *(.)* is the cumulative normal distribution

[1] Following Ederington and Lee (1996) and Linn and Zhu (2004), we define return volatility as the absolute deviation of return from its mean. For log-normally distributed return series, this absolute deviation is proportional to standard deviation (Linn and Zhu, 2004).

function. As in Ederington and Lee (1996), we analyze the change in implied volatility, CIV_t, which is calculated as:

$$CIV_t = 100 \text{ x } ln\,(\sigma_t/\sigma_{t-1}), t = 1, 2, \ldots, T \quad (7)$$

3.3 Inventory Reports

3.3.1 Weekly Petroleum Status Report

EIA publishes "Weekly Petroleum Status Report" every Wednesday at 10:30 am EST (or on Thursday at 11:00 am EST for the weeks including federal holidays on Wednesdays). This report provides information on the inventory levels of crude oil and refinery products as of previous Friday. Release dates of these reports are collected from the EIA's website and by personal communication with the EIA staff. There are total of 777 reports during the sample period, and 666 of those are on Wednesday, 108 on Thursday, and only three on Friday. All reports are released during the trading hours.

3.3.2 Weekly Natural Gas Storage Report

The American Gas Association (AGA) conducted a weekly survey on inventory levels of working gas from a sample of operators along the petroleum supply chain and compiled those estimates into reports. These reports are published by AGA from January 5, 1994 to May 1, 2002. Since then, EIA has taken over the responsibility of the survey and has been publishing "Weekly Natural Gas Storage Report" every Thursday at 10:30 am EST (on Wednesday at 12:00 pm EST or on Friday at 10:30 am EST for the weeks including federal holidays on Tuesday and Thursday). The report tracks the U.S. total working gas in underground storage as of previous Friday. Release dates of these reports are collected from the EIA's website. Of the total 748 natural gas storage reports during the study period, 535 are on Thursday, 202 on Wednesday, 10 on Friday, and only one on Monday. Of the total reports, 88 are released between 4:00 and 4:45

pm EST (i.e. after the trading ends), and 660 between 10:30 am and 2:00 pm EST (i.e. during the trading hours).

3.4 Macroeconomic Announcements

The Federal Reserve releases the “Industrial Production and Capacity Utilization” report every month, tracking output, capacity, and capacity utilization in the U.S. industrial sector. In addition, the Bureau of Labor Statistics, an agency of U.S. Department of Labor releases the “Employment Situation” report on the first Friday of each month. These reports contain the number of people in the labor force, employment and unemployment rates, and reasons for unemployment. Release dates of these reports are collected from their respective websites. During the sample period, the number of reports for industrial production and employment are 179 each and all of those reports are released before the trading starts. The employment report is mostly released on Fridays with only five on Thursday and one on Monday. However, the release day of industrial production is spread across all weekdays. Of the total 179 reports, 62 are released on Friday, 44 on Wednesday, 39 on Tuesday, 20 on Thursday, and 14 on Monday.

3.5 Descriptive Statistics

Table 2 presents the summary statistics of the return volatility and daily change in implied volatility for all three commodities. The Jarque-Bera, Phillips-Perron, Ljung-Box, and Engle’s Lagrange multiplier (LM) test for normality, stationarity, serial correlation, and autoregressive conditional heteroskedasticity (ARCH), respectively, are also reported. It can be seen that natural gas experienced the highest average return volatility (2.330) over the sample period. The differences in volatility might be due to seasonality in consumption. For instance, most of the natural gas is used for heating purposes whose demand is seasonal in nature, whereas crude oil is mostly used in the industrial sector whose demand is less seasonal. For all three commodities, the normality of and the existence of a unit root in their return volatility series are rejected. Moreover, each series is serially correlated based on the Ljung-Box test. We find a similar pattern in the change in implied volatility. Natural gas has the highest change in implied volatility. We reject the normality and unit root and detect autocorrelation in all three commodities.

Tables 3 and 4 report the summary statistics of return volatility and daily change in implied volatility on announcement and non-announcement days. There are a total of 1,638 days with any of the four reports considered and 2,103 days without any of these reports. It should be noted that non-announcement days might contain any other reports not considered in this study. Of these 1, 638 announcement days, 237 days have more than one report.

We can see from Table 3 that the average return volatility is higher on announcement days than that on non-announcement days for all three commodities. For crude oil, the mean return volatility is higher compared to non-announcement days only on the days with petroleum status and natural gas storage reports. In addition to these two reports, days with employment report releases exhibit higher average return volatility, for heating oil. Natural gas return volatility; on the other hand, is higher on days with industrial production, petroleum status, and natural gas storage reports compared to non-announcement days.

Table 4 shows that implied volatility decreases on the days of announcements compared to non-announcements. Reduction in implied volatility implies that relevant uncertainties are resolved with the releases of these reports. Taking a closer look at individual reports demonstrates that the implied volatility of crude oil and natural gas decreases on days of each report's release compared to non-announcement days. For heating oil, on the other hand, implied volatility decreases only on days of petroleum status and natural gas storage reports releases.

CHAPTER 4

METHODOLOGY

We begin our empirical analysis by addressing the question; - Do return volatility and implied volatility vary substantively on days with publicly scheduled announcements compared to non-announcement days? We first conduct preliminary analysis using both parametric (*t*-test) and non-parametric (Kruskal Wallis H-test) approaches following the previous literature (Ederington and Lee, 1996). To further shed light on the impact of particular reports, we use a regression analysis to measure the reaction of the market to each individual report. Since multiple announcements are considered for this study, the regression approach allows us to simultaneously estimate the effect of each report by creating separate dummy variables for their release days. However, event clustering bias might be a possible concern, but as long as all relevant report release days are included in the regression, estimated coefficient should reflect their impact (Karali, 2012).

4.1 Preliminary Analysis

The first test we use for preliminary analysis is Kruskal Wallis-H test (K-W test), a non-parametric approach. The K-W test enables comparison of the distributions, without relying on the normality assumption of the underlying variable (Kruskal and Wallis, 1952). The test ranks all the individual observations in all groups and calculates the sum of ranks in each group which indicates how the groups are different from each other. The K-W test statistic is simply calculated as follows:

$$W = \frac{12}{N(N+1)} \sum_{i=1}^{k} \frac{Z_i^2}{n_i} - 3(N+1) \quad (8)$$

where, N $(\sum n_i)$is total number of observation, Z_i is sum of ranks of data from each group, K is number of groups, and n_i is number of observations in each group.

A larger value of the test statistic leads to rejection of the null hypothesis. Under the null hypothesis, the K-W test is asymptotically Chi-squared distributed with k-1 degrees of freedom. In our study, we test the null hypothesis that the distributions of the return volatility and change in implied volatility on days with announcements are equal to the distributions of those on days with no announcements. If the volatilities on announcement days have a different distribution than non-announcement days, then the evidence favors the price discovery role in derivative market and usefulness of the particular announcements.

The second test is a Welch's t-test, which is an adaptation of the Student's t-test. Welch's t-test is typically used for the samples with different variances and unequal sample size. Welch's t-test statistics is defined as:

$$t = \frac{X_1 - X_2}{\sqrt{\frac{S_1^2}{N_1}} + \sqrt{\frac{S_2^2}{N_2}}}, \quad (9)$$

where $\bar{X}_{i,}$ S_i^2 and N_i are the sample i's mean, variance and size, respectively. The degree of freedom υ associated with the test statistic is given as:

$$\upsilon = \frac{\left(\frac{S_1^2}{N1} + \frac{S_2^2}{N2}\right)^2}{\frac{S_1^4}{N_1^2 \upsilon_1} + \frac{S_2^4}{N_2^2 \upsilon_2}} \quad (10)$$

where $\upsilon_1 = N_1 - 1$ and $\upsilon_2 = N_2 - 1$.

Once these test statistics are computed they are used with the t-distribution to test the null hypothesis that two population means are equal. The approximate degree of freedom is rounded to nearest integer. Using this test, we test the difference between mean return volatility and change in implied volatility on the days of announcements and no announcements.

4.2 Regression Analysis (AR-GARCH Model)

Regression models have been extended in literature to accommodate the distributional characteristics of commodity futures return data within a GARCH framework (Myers and Hanson, 1993; Goodwin and Schnepf, 2000). It has been well documented in the literature that OLS assumptions are violated as commodity futures return series exhibit non-normality and volatility clustering (Narayan and Narayan, 2007). GARCH model allows for time-varying conditional volatility (Bollerslev, 1986). For the return volatility and change in implied volatility series, we find strong evidence for volatility clustering (Figures 2 and 3), non-normality, and serial correlation (Table 1). Also to test for conditional heteroskedasticity, we use the ARCH test suggested by Engle (1982) with the null hypothesis of no ARCH effect. We reject the null hypothesis for all three commodities suggesting the presence of conditional heteroskedasticity (Table 2). To account for heteroskedasticity, we model our volatility series within a GARCH framework. We adopt a GARCH (1,1) model with the Student-t distribution to capture the fat tailed property of the series. Also, to account for serial correlation in the series, we use the lagged terms in the conditional mean equations and separately estimate an AR(5)-GARCH(1,1) model for each of the three commodities.

Mean equations for each series in our study are defined as a function of their lagged values, dummy variables representing the days of the report releases and a random disturbance term. Variance equations are defined as a function of squared past residuals and the past variance. The AR(5)-GARCH(1,1) models employed in the study are as follows.

Mean and variance equation for return volatility:

$$RV_t = a + \sum_{p=1}^{5} b_p \, RV_{t-p} + \sum_{j=1}^{4} \beta_j \, D_{jt} + \epsilon_t, \tag{11}$$

$$\epsilon_t = z_t \sqrt{h_t}, \; z_t \sim t_{\nu_z}, \tag{12}$$

$$h_t = \omega + \gamma \epsilon_{t-1}^2 + \delta h_{t-1} \tag{13}$$

Mean and variance equation for change in implied volatility:

$$CIV_t = \tau + \sum_{p=1}^{5} \theta_p \, CIV_{t-p} + \sum_{j=1}^{4} \varphi_j \, D_{jt} + \varepsilon_t, \tag{14}$$

$$\varepsilon_t = \mu_t \sqrt{w_t}, \; \mu_t \sim t_{\nu_\mu}, \tag{15}$$

$$w_t = \lambda + \pi \varepsilon_{t-1}^2 + \vartheta w_{t-1}, \tag{16}$$

where ϵ_t and ε_t are regression error terms. The variables z_t and μ_t are random variables that follow Student's t distribution with their respective degrees of freedom ν_z and ν_μ. The dummy variables, D_{jt}, take the value of one on the day of announcement, and zero otherwise. The coefficients β_j and φ_j provide the estimates of the report *j*'s impact on return volatility and implied volatility, respectively.

4.3 Hypotheses

Hypothesis I: Return volatility tends to rise on the day of publicly scheduled announcements. According to the efficient market hypothesis, relevant new information in publicly scheduled announcements will be immediately incorporated into prices. As a result of this price adjustment process, return volatility is hypothesized to be higher on announcement days and thus the coefficient β_j in equation (11) is expected to be positive.

Hypothesis II: Implied volatility tends to fall on the day of publicly scheduled announcements. As a resolution of uncertainty, we hypothesize that implied volatility will fall on the day of important scheduled announcements and thus the coefficient φ_j in equation (14) is expected to be negative.

CHAPTER 5

EMPIRICAL RESULTS

We first present the results of preliminary analysis where we test for the equality of means and distributions of the return volatility and change in implied volatility on announcement and non-announcement days. Then we present the results from regression analysis where we analyze in detail the impact of particular report releases.

5.1 Preliminary Results

5.1.1 Return Volatility on Scheduled Announcement Days

Before moving on to the particular effect of announcements, we provide an insight into the evidence supporting Hypothesis I. In Figure 4, the cumulative distribution functions of return volatility on announcement and non-announcement days are presented. Results show that the distributions of daily return volatility of crude oil and heating oil are not identical on days with scheduled announcements compared to days with no announcements. However, there is no difference in the distribution of daily return volatility of natural gas across the announcement and non-announcement days. Other market moving events might have occurred in the natural gas futures market on the days without reports considered, rendering no difference among the two distributions.

Table 5 presents the results on K-W tests and *t*-tests on return volatility. In crude oil futures market, the daily return volatility distributions are significantly different on the days with petroleum status and natural gas storage report releases compared to days without reports. However, the distribution of crude oil return volatility on the days of macroeconomic announcements does not differ significantly from the days with no scheduled announcements. This implies that the macroeconomic announcements do not have any significant impact on the distribution of return volatility. Crude oil return volatility is 1.755, an average, on the day of scheduled announcements which is higher than the days with no announcements. Also, the mean crude oil return volatility is higher on the release days of petroleum status and natural gas storage reports (1.831 and 1.788, respectively) than it is on the non-announcement days (1.607).

We observe a similar pattern in the heating oil futures market. When comparing the days with macroeconomic announcements to the days without announcements, we do not find any significant differences in the distribution of heating oil return volatility. Whereas the distributions of daily return volatility significantly differ on the days with petroleum status and natural gas storage report releases compared to the days without scheduled announcements. The mean return volatility on the days of petroleum status and the natural gas storage report is 1.771 and 1.748, respectively, which is higher than the mean return volatility of 1.561 on the days without any considered announcements.

Results show that employment situation report has a non-trivial impact on the distribution of natural gas return volatility. However, the mean return volatility of natural gas on the day of employment report is lower as compared to the days without announcements, which is not consistent with Hypothesis I. This might be due the day-of-the-week effect which is investigated below. The distribution of return volatility shows a significant difference on the days with natural gas storage report releases, with higher mean return volatility (2.785) as compared to days with no considered announcements (2.294).

5.1.2 Change in Implied Volatility on Scheduled Announcement Days

The cumulative distribution functions of changes in implied volatility on announcement and non-announcement days are shown in Figure 5. Results show that the distributions of change in implied volatility are not identical on days with scheduled announcements compared to days with no announcements in all three markets.

Results from Table 6 provide evidence for Hypothesis II. The distribution of changes in implied volatility differs significantly on the scheduled announcement days than on non-announcement days, and the implied volatility falls on the day of important scheduled announcements.

In the crude oil options market, change in implied volatility has different distributions on announcement days compared to days without announcements. The implied volatility rises by an average of 0.365 percentage points on days with no scheduled announcements, and falls by an average of 0.309 percentage points on days with at least one of the considered announcements. From the results, it is clear that weekly petroleum status and natural gas storage reports have strong impacts in the crude oil options market. The implied volatility falls by 0.407 and 0.419 percentage points, respectively on the days with petroleum status report and natural gas storage report releases. None of the macroeconomic announcements are found to have a significant effect on crude oil options market.

Similar to crude oil, none of the macroeconomic announcements show a significant impact in heating oil options market. The distributions of changes in implied volatility on the days with scheduled announcements and no announcements statistically differ from each other. The implied volatility increases by an average of 0.182 percentage points on days without any of the considered announcements and declines by an average of 0.146 percentage points on days with at least one of the scheduled announcements. The median of the change in implied volatility differs along with the release of both petroleum status, and natural gas storage reports whereas the mean is statistically different only on the release days of natural gas storage report. On the days with natural gas storage reports, the implied volatility falls by an average of 0.332 percentage points.

Looking at the natural gas market in Table 6, the distribution of changes in implied volatility statistically differs on the days with scheduled announcements and non-announcements. The medians differ on the release days of employment situation, petroleum status, and natural gas storage reports. However, the *t*-test statistics show that change in implied volatility significantly differs only on the days with natural gas storage report. The implied volatility falls by an average of 0.194 percentage points on announcement days whereas it rises by an average of 0.482 percentage points on non-announcement days. With the releases of the natural gas storage report, implied volatility decreases by an average of 0.912 percentage points.

5.2 Regression Results

5.2.1 Impact of Scheduled Announcements on Return Volatility

5.2.1.1 Crude Oil

Results in Table 7 show while petroleum status and natural gas storage reports have a significant impact on the crude oil return volatility; none of the macroeconomic reports have an impact. This result is consistent with previous findings (Roaache and Rossi, 2010; Killian and Vega, 2011), where it is found that variation in crude oil prices is left unexplained by most of the macroeconomic announcements including employment and industrial production reports. The petroleum status report has the greatest impact, 0.155, followed by the natural gas storage report with coefficient 0.090. Consistent with our Hypothesis I, their signs are positive suggesting that the return volatility increases on release days of these two reports. The results are in line with the findings in Bu (2014), where crude oil prices are shown to significantly react to the crude oil inventory reports. Our result is also supported by the findings of Halova, Alexander, and Kucher (2014) where the authors find that changes in natural gas inventories move crude oil futures returns. All five lags of return volatility are statistically significant, with positive coefficients. Results imply that the variance of the crude oil returns on the day with petroleum status report release is $(a + \beta_j/a)^2 = 1.27$ times the variance on the day with no scheduled announcements and the ratio is 1.15 on the release days of natural gas storage reports.

The constant conditional variance is 0.024 and is statistically significant at the 1% level. The ARCH parameter estimate (γ) of 0.027 implies that any shocks in the previous period produce disturbance in the market increasing the variance (second moment) of the return volatility. The GARCH parameter estimate (δ) of 0.959 suggests that the variance of return volatility in the previous period has a large effect on the variance of volatility in the current period and is highly persistent.

5.2.1.2 Heating Oil

Similar to crude oil, the two inventory reports significantly affect the return volatility, and macroeconomic announcements have no explanatory power. Heating oil futures have a significant constant return volatility of 1.165. Petroleum status report has the greatest impact with a positive coefficient of 0.173, followed by the natural gas storage report with a coefficient estimate of 0.099. Results are in line with the previous findings. Halova, Alexander, and Kucher (2014), for instance, find significant responses in heating oil returns to crude oil and natural gas inventory reports. Positive coefficients provide support for our proposed Hypothesis I. Calculated from the coefficient estimates, the variance of heating oil returns on the days with petroleum status report release is 1.32 times the variance on the days without announcements. Similarly, for the natural gas storage report, the ratio is 1.18. All autoregressive terms are statistically significant with positive coefficient estimates.

Heating oil return volatility has a constant conditional variance of 0.010, which is statistically significant at the 1% level. The ARCH parameter estimate of 0.021 indicates that any disturbances (news, shocks) in heating oil futures market in the previous period increases the current variance of futures return volatility. The GARCH parameter estimate of 0.972 signals that variance of return volatility is highly persistent.

5.2.1.3 Natural Gas

Average return volatility of natural gas is 1.753. Unlike crude and heating oil, employment report is found to have a significant effect on natural gas return volatility. Surprisingly, the coefficient estimate is negative, which contradicts Hypothesis I which asserts that return volatilities are expected to increase on the report release days. We see the opposite result in the natural gas futures market, although it is significant only at the 10% level. One possible explanation might be the day-of-the-week effect, which causes return volatility to drop on the day of release of employment report. Among inventory reports, natural gas report significantly impacts return volatility with the coefficient estimate of 0.418, reflecting an increase in the return volatility on the report release day. The results are consistent with Linn and Zhu (2004), who reported significant increase in natural gas futures return volatility with the release of natural gas inventory report. Our results provide no evidence for the natural gas to be affected by petroleum status reports. This contrasts with Wolfe and Rosenman (2014), who find bidirectional causality using intraday data. They find the effect of natural gas inventory reports on crude oil price volatility to be more than twice of the effect of crude oil inventory reports on natural gas price volatility. Contradictory result might be due to the difference in frequency of the data and methodology used. Our study considers only the report release days whereas the previous study accounts for the surprise content of the reports. Results also indicate that the variance of natural gas returns on the days with natural gas storage reports is 1.53 times the variance on the day with no announcements. Positive autocorrelation in return volatility is found in all five lags.

The constant conditional variance is 0.124. The ARCH parameter estimate of 0.043 is statically significant at the 1 % level and substantially greater compared to crude and heating oil. This suggests that any disturbance in the natural gas market increases the future return volatility more than the other two markets do. The GARCH parameter estimate is 0.924, indicating that the variance in return volatility is highly persistent. However, the level of persistence is lower compared to crude and heating oil markets. Karali and Ramirez (2014) also found lower level of volatility persistence in the natural gas market compared to the other two markets.

5.2.2 Impact of Scheduled Announcements on Change in Implied volatility

5.2.2.1 Crude Oil

Table 8 shows that implied volatility of crude oil increases by 0.164 percentage points, on average, on days without scheduled announcements. This result is supported by the findings of Ederington and Lee (1996). In interest rate and exchange markets, they find that implied volatility increases on the days with no scheduled announcements. Consistent with the results from futures market, none of the macroeconomic announcements are found to affect implied volatility. The two inventory reports, on the other hand, have statistically significant impact on implied volatility. Release of natural gas storage reports decreases the implied volatility by 0.709 percentage points. Similarly, the release of petroleum status report decreases implied volatility by 0.597 percentage points. Both estimates are statistically significant at the 1 % level and their negative signs are consistent with Hypothesis II.

Conditional variance is 1.565 and significant at the 1 % level. The ARCH parameter estimate (π) of 0.134 indicates that shocks to the crude oil market in the past increases the current variance. The GARCH parameter estimate (ϑ) of 0.797 indicates the degree of persistence in the variance.

5.2.2.2 Heating Oil

Among the considered reports, only the release of petroleum status report negatively impacts the implied volatility. Consistent with Hypothesis II, it indicates that the implied volatility falls, on average, by 0.171 percentage points with the release of petroleum status report.

The ARCH parameter estimate is 0.711, and considerably higher than the ARCH parameters in the other two markets. This indicates that past shocks in the heating oil market increase the current variance more as compared to other two markets. The GARCH parameter estimate is 0.277, which is quite smaller, revealing that the variance in the past period has a smaller effect on the variance in the current period as compared to other two markets.

5.2.2.3 Natural Gas

Table 8 shows that the change in implied volatility of natural gas is, on average, 0.277, and statistically significant at the 1% level. Similar to the return volatility, employment report is found to significantly impact the implied volatility. This result is consistent with the findings of Chan and Gray (2017), where they find that jumps in natural gas futures price (return volatility) are significantly affected by employment reports. Results indicate that implied volatility decreases by 0.499 percentage points with the release of the employment report. The natural gas storage report has the greatest impact with a drop of 1.542 percentage points on the release day. Only the first autoregressive term is significant with a positive coefficient.

Change in implied volatility has a conditional variance of 2.55 and is statistically significant at the 1% level. The coefficient on ARCH parameter is 0.210 indicating that past shocks in natural gas market increases the current variance. The GARCH parameter estimate of 0.640 indicates persistent nature of variance.

5.3 Day-of-the-week Effect

There is empirical evidence that the futures price volatilities are higher on Mondays and lower on Fridays than any other weekdays (Murry and Zhu, 2004; Mu, 2007). Tables 9 through 11 show results of the F-tests with the null hypothesis of equality of means on all weekdays for the three categories: all days, days with scheduled announcements, and days without announcements. Following Ederington and Lee (1996), the means on Tuesday through Thursday (denoted T-R thereafter) are averaged and then its equality is tested against the mean on Monday and on Friday for all three categories. The means on each weekday with scheduled announcements are also compared with weekdays on non-announcement days using Welch's t-test.

Consider the results for crude oil first. In Table 9, the F-test suggests that we reject the null hypothesis of equal means across all weekdays for all days and days with scheduled announcements, but we fail to reject the null in the case of no announcements. Inequality in means of announcement days and all days is mostly attributed to uneven spread of announcements across weekdays. We also see that Monday mean is significantly greater than T-R mean for days with scheduled announcements, but not for the other two categories. Friday mean is lower than that of T-R group mean for all the three categories. Results provide no strong evidence for the existence of a day-of-the-week effect in crude oil futures market. If this effect exists, then we should have rejected the null hypothesis of the joint F-test on days without scheduled announcements and also Monday mean should have been greater than T-R mean for the same category. The results are different than previous studies (Auer, 2014; Karali and Ramirez, 2014), where Monday volatility is found to be higher than other days. However, Ederington and Lee (1996) find that the volatility of interest rate and foreign exchange futures on Mondays to be same as other weekdays when there are no macroeconomic news announcements. From Table 9, we can see that change in implied volatility for crude oil differs significantly across weekdays for all days and days without announcements. However, this is not true in the case of days with scheduled announcements. Also, Monday mean is greater and Friday mean is lower as compared to T-R mean for days with no announcements. Thus, results provide strong evidence for the existence of a day-of-the-week effect in crude oil options market.

In the case of heating oil (Table 10), return volatility significantly differs across weekdays on days with scheduled announcements and on all days. However, we fail to reject the null of the joint F-test for the days with no announcements. Although Monday mean is higher than T-R mean, Friday mean does not differ significantly on non-announcement days. Results provide no strong evidence for the existence of a day-of-the-week effect in heating oil futures market. We observe similar results from the joint F-test for change in implied volatility. Changes in implied volatility are jointly different across weekdays for all days and days with announcements. We see that Monday mean is higher whereas Friday mean does not differ significantly from the T-R mean for all the three categories. Like futures market, heating oil does not provide evidence for daily seasonality in the options market.

For natural gas (Table 11), the F-tests on the equality of means on return volatility across weekdays show that at least one of the weekdays is different when considering all days and non-announcement days. Results provide evidence of higher Monday mean and lower Friday mean when compared to T-R mean for the non-announcement days supporting the existence of a day-of-the-week pattern in the natural gas futures market. Our findings are consistent with those of Mu (2007), where the author finds that natural gas futures volatility exhibits day-of-the-week pattern with Mondays being higher and Fridays being lower. Similar results are observed for the change in implied volatility. It can also be seen that although Monday mean is higher, Friday mean does not differ from the T-R mean for all the three categories. Results do not provide strong evidence for the existence of a day-of-the-week effect in natural gas options market.

CHAPTER 6

CONCLUSIONS AND IMPLICATIONS

During the last decade, energy markets have experienced large price fluctuations. Inventory and macroeconomic news are considered important factors in determining energy price volatility. A number of previous studies have examined their impact on energy futures market. Surprisingly, less has been studied about the impact of inventory and macroeconomic news in energy options market. Implied volatility, volatility implied by options prices, is essential to study because it is a forward-looking measure of uncertainty and a key factor in pricing options.

This study examines the response of both return volatility and implied volatility in energy markets, crude oil, heating oil, and natural gas, to the scheduled news announcements using daily data for the period spanning from 1998 through 2013. The release of inventory reports namely, Weekly Petroleum Status Report, and Weekly Natural Gas Storage Report, and macroeconomic reports, Employment Situation Report, and Industrial Production and Capacity Utilization Report, are the considered scheduled announcements. Preliminary analysis is conducted using parametric and non-parametric statistical tests such as the t-test, and Kruskal Wallis test. Further, the impact of individual announcements is estimated using an AR (5)-GARCH (1, 1) model with Student-t distributed error term.

Our study show that return volatility tends to increase whereas implied volatility tends to decrease on the days of important scheduled announcements with an exception of natural gas return volatility. Increase in return volatility suggests that the announcements reveal the information about the commodity and the market participants incorporate that information into futures prices triggering more volatility. Drop in implied volatility reveals that the announcements help to resolve uncertainty associated with the commodity. In addition, results show that the return volatility and change in implied volatility in crude and heating oil are influenced by the release of both the inventory reports. Since, petroleum report tracks the supply estimates of both crude and heating oil, its release affects both markets. Also, heating oil is a byproduct of crude oil and any information affecting crude oil directly impacts heating oil. Heavy reliance of the U.S. petrochemical industry on natural gas as a primary feedstock for crude oil refinery operations can be a possible explanation for natural gas storage report affecting crude and heating oil volatility (Huntington, 2007). As long as there is demand for natural gas for refinery, increase in value of the refined products increases the demand for crude oil and natural gas. Thus, inventory report affecting the price of natural gas also affects the price volatility of heating oil and refinery products, which, in turn, affects crude oil volatility. However, no compelling evidence is found in favor of petroleum report affecting natural gas market. Moreover, we find no evidence for the macroeconomic reports' impact on crude and heating oil volatilities. Findings also reveal that one of the macroeconomic announcements, employment situation report is found to significantly influence the return volatility and implied volatility in the natural gas market.

We also identify significant ARCH and GARCH effects in both futures and options markets for all three commodities. Furthermore, we also find strong evidence for the existence of a day-of-the-week pattern in crude oil options market, and in natural gas futures market whereas no evidence is found for a weekday pattern in heating oil in futures and options markets.

Our results have several implications for commodity traders and market regulators. First, significant impact of inventory report to market implies some informational value in those reports supporting the fact that large fluctuations in energy prices are explained by the shift in demand and supply estimates. Secondly, understanding volatility dynamics on scheduled announcements and weekdays would help commercial traders to understand the price movement and establish their trading strategies to manage their price risk.

REFERENCES

Alquist, R. and Kilian, L. 2010. “What Do We Learn from the Price of Crude Oil Futures?” *Journal of Applied Econometrics* 25:539-573.

Auer, B. R. 2014. “Daily Seasonality in Crude Oil Returns and Volatilities.” *Energy Economics* 43:82-88.

Basistha, A. and Kurov, A. 2015. “The Impact of Monetary Policy Surprises on Energy Prices.” *Journal of Futures Markets* 35:87–103.

Belgacem, A., Creti, A., Guesmi, K., and Lahiani, A. 2015. “Volatility Spillovers and Macroeconomic Announcements: Evidence from Crude Oil Markets.” *Applied Economics* 47(28):2974-2984.

Black, F. 1976. “The Pricing of Commodity Contracts.” *Journal of Financial Economics* 3(1-2): 167-179.

Bollerslev, T. 1986. “Generalised Autoregressive Conditional Heteroskedasticity.” *Journal of Econometrics* 31:307–327.

Bu, H. 2014. “Effect of Inventory Announcements on Crude Oil Price Volatility.” *Energy Economics* 46:485-494.

Chan, K.F. and Gray, P. 2017. “Do Scheduled Macroeconomic Announcements Influence Energy Price Jumps?” *Journal of Futures Markets* 37(1):71-89.

Chang, C., Daouk, H., and Wang, A. 2009. “Do Investors Learn about Analyst Accuracy? A Study of the Oil Futures Market.” *Journal of Futures Markets* 29:414–429.

Chatrath, A., Miao, H., and Ramchander, S. 2012. “Does the Price of Crude Oil Respond to Macroeconomic News?” *Journal of Futures Markets* 32:536–559.

Demirer, R. and Kutan, A.M. 2010. “The Behavior of Crude Oil Spot and Futures Prices around OPEC and SPR Announcements: An Event Study Perspective.” *Energy Economics* 32:1467-1476.

Ederington, L. H. and Lee, J. H. 1996. “The Creation and Resolution of Market Uncertainty: The Impact of Information Releases on Implied Volatility.” *Journal of Financial and Quantitative Analysis* 31(4):513-539.

Elder, J., Miao, H., and Ramchander, S. 2013. “Jumps in Oil Prices: The Role of Economic News.” *Energy Journal* 34:217–237.

Fleming, J., Ostdiek, B. 1999. “The Impact of Energy Derivatives on the Crude Oil Market.” *Energy Economics* 21 (2):135–167.

Goodwin, B. K. and Schnepf, R. 2000. “Determinants of Endogenous Price Risk in Corn and Wheat Futures Markets.” *Journal of Futures Markets* 20 (8):753–774.

Halova, M. W., Alexander, K., and Kucher, O. 2014. “Noisy Inventory Announcements and Energy Prices.” *Journal of Futures Markets* 34(10):911-933.

Hertel, T. W. and Beckman, J. 2011. “Commodity Price Volatility in the Biofuel Era: An Examination of the Linkage between Energy and Agricultural Markets.” NBER Paper Series, Working Paper No. 16824.

Horan, S. M., Peterson, J. H., and Mahar, J. 2004. “Implied Volatility of Oil Futures Options Surrounding OPEC Meetings.” *Energy Journal* 25(3):103–125.

Huntington, H. G. 2007. “Industrial Natural Gas Consumption in the United States: An Empirical Model for Evaluating Future Trends.” *Energy Economics* 29(4):743-759.

Isengildina, O., Irwin, S. H., Good, D. L., and Gomez, J. K. 2008. "Impact of WASDE Reports on Implied Volatility in Corn and Soybean Markets." *Agribusiness* 24:473–490.

Karali, B. 2012. "Do USDA Announcements Affect Co-movements across Commodity Futures Returns?" *Journal of Agricultural and Resource Economics* 37:77-97.

Karali, B. and Power, G.J. 2013. "Short-and Long-Run Determinants of Commodity Price Volatility." *American Journal of Agricultural Economics* 95(3):724-738.

Karali, B. and Ramirez, O. A. 2014. "Macro Determinants of Volatility and Volatility Spillover in Energy Markets." *Energy Economics* 46:413-421.

Kilian, L. and Murphy, D. 2014. "The Role of Inventories and Speculative Trading in the Global Market for Crude Oil." *Journal of Applied Econometrics* 29:454–478.

Kilian, L. and Vega, C. 2011. "Do Energy Prices Respond to U.S. Macroeconomic News? A Test of the Hypothesis of Predetermined Energy Prices." *Review of Economics and Statistics* 93:660-671.

Kruskal, W. H. and Wallis, W. A. 1952. "Use of Ranks in One Criterion Variance Analysis." *Journal of American Statistics Association* 47:583-621.

Lee, T. K. and Zyren, J. 2007. "Volatility Relationship between Crude Oil and Petroleum Products." *Atlantic Economic Journal* 35:97–112.

Linn, S. C. and Zhu, Z. 2004. "Natural Gas Prices and the Gas Storage Report: Public News and Volatility in Energy Futures Market." *Journal of Futures Markets* 24:282-313.

Miao, H., Ramchander, S., Wang, T., and Yang, J. 2017. "The Impact of Crude Oil Inventory Announcements on Prices: Evidence from Derivatives Markets." *Journal of Futures Markets* 00:1-28.

Mu, X. 2007. “Weather, Storage, and Natural Gas Price Dynamics: Fundamentals and Volatility.” *Energy Economics* 29 (1):46–63.

Murry, D. and Zhu, Z. 2004. “Enron Online and Informational Efficiency in the U.S. Natural Gas Market.” *Energy Journal* 25 (2):57–74.

Myers, R. J. and Hanson, S. D. 1993. “Pricing Commodity Options When the Underlying Futures Price Exhibits Time-Varying Volatility.” *American Journal of Agriculture Economics* 75 (1):121–130.

Narayan, P. K. and Narayan, S. 2007. “Modelling Oil Price Volatility.” *Energy Policy* 35(12):6549–6553.

Nikkinen, J. and Sahlstrom, P. 2004. “Impact of the Federal Open Market Committee's Meetings and Scheduled Macroeconomic News on Stock Market Uncertainty.” *International Review of Financial Analysis* 13:1–12.

Nikkinen, J., Sahlstrom, P., and Vahamaa, S. 2006. “Implied Volatility Linkages among Major European Currencies.” *Journal of International Financial Markets, Institutions and Money* 16(2):87-103.

Pindyck, R. S. 2001. “The Dynamics of Commodity Spot and Futures Markets: A Primer.” *Energy Journal* 22(3):1–29.

Pindyck, R.S. 2004. “Volatility in Natural Gas and Oil Markets.” *Journal of Energy and Development* 30(1):1-19.

Regnier, E. 2007. “Oil and Energy Price Volatility.” *Energy Economics* 29:405–427.

Roache, S. K. and Rossi, M. 2010. “The Effects of Economic News on Commodity Prices.” *Quarterly Review of Economics and Finance* 50:377–385.

Sanders, D. R., and Irwin, S. H. 2010. “A Speculative Bubble in Commodity Futures Prices? Cross-sectional Evidence.” *Agricultural Economics* 41:25-32.

Sanders, D. R., Irwin, S. H. 2011. “New Evidence on the Impact of Index Funds in U.S. Grain Futures Markets.” *Canadian Journal of Agricultural Economics* 59:519–532.

Suenaga, H. and Smith, A. 2011. “Volatility Dynamics and Seasonality in Energy Prices: Implications for Crack-Spread Price Risk.” *Energy Journal* 32 (3):27–58.

Suenaga, H., Smith, A., and Williams, J. 2008. “Volatility Dynamics of NYMEX Natural Gas Futures Prices.” *Journal of Futures Markets* 28(5):438–463.

Szakmary, A., Ors, E., Kim, J. K., and Davidson, W. N. 2003. "The Predictive Power of Volatility: Evidence from 35 Futures Markets." *Journal of Banking and Finance* 27(11): 2175.

Tang, K. and Xiong, W. 2012. “Index Investment and the Financialization of Commodities.” *Financial Analysts Journal* 68:54–74.

Wolfe, M. H. and Rosenman, R. 2014. “Bidirectional Causality in Oil and Gas Markets.” *Energy Economics* 42:325-331.

Ye, S., Karali, B., and Ramirez, O.A. 2014. “Event Study of Energy Price Volatility: An Application of Distributional Event Response Model.” Agricultural and Applied Economics Association Annual Meeting, Minneapolis, Minnesota. July 27-29

Ye, S. and Karali, B. 2016. “The Information Content of Inventory Announcements: Intraday Evidence from Crude Oil Futures Market.” *Energy Economics* 59:349-364.

Table 1. Futures and Options Contracts Used in Each Calendar Month

Calendar Months	Futures contracts	Options contracts
January	March (H)	March (H)
February	April (J)	April (J)
March	May (K)	May (K)
April	June (M)	June (M)
May	July (N)	July (N)
June	August (Q)	August (Q)
July	September (U)	September (U)
August	October (V)	October (V)
September	November (X)	November (X)
October	December (Z)	December (Z)
November	January (F)	January(F)
December	February (G)	February(G)

Note: Letters in parenthesis are the code for contracts that expire in a particular month.

Table 2. Summary Statistics of Volatility Measures

Return Volatility $\lvert R_t - \overline{R} \rvert$	Crude Oil	Heating Oil	Natural Gas
No. of observation	3741	3741	3741
Mean	1.672	1.625	2.330
Median	1.280	1.266	1.794
Std. deviation	1.504	1.409	2.036
Minimum	0.000	0.000	0.001
Maximum	16.581	14.007	18.875
Jarque-Bera normality test	1.4×10^4	5969	5819
	(0.000)	(0.000)	(0.000)
Phillips-Perron unit root test	-50.517	-53.470	-56.353
	(0.000)	(0.000)	(0.000)
Ljung Box serial correlation test	1283.116	743.988	558.707
	(0.000)	(0.000)	(0.000)
ARCH LM test	169.637	122.847	149.461
	(0.000)	(0.000)	(0.000)
Change in Implied Volatility 100 x $ln\ (\sigma_t/\sigma_{t-1})$			
No. of observation	3736	3730	3737
Mean	0.069	0.038	0.186
Median	-0.097	0.000	0.006
Std. deviation	4.346	5.631	4.102
Minimum	-20.509	-158.425	-53.963
Maximum	40.748	160.856	49.427
Jarque-Bera normality test	6490	1.9×10^7	1.4×10^5
	(0.000)	(0.000)	(0.000)
Phillips-Perron unit root test	-55.109	-81.003	-65.635
	(0.000)	(0.000)	(0.000)
Ljung Box serial correlation test	75.164	345.424	99.403
	(0.000)	(0.000)	(0.000)
ARCH LM test	340.461	521.285	741.315
	(0.000)	(0.000)	(0.000)

Note: Daily data from 7/1/1998 through 6/5/2013 are utilized. The null hypothesis of the Jarque-Bera test is the series is normally distributed. The null hypothesis of the Phillips-Perron test is the existence of a unit root in the series. The null hypothesis of the Ljung-Box test is no serial correlation. The null hypothesis of the ARCH LM test is no ARCH effects. The p-values of the test statistics are reported in parentheses.

Table 3. Summary Statistics of Return Volatility on Announcement and Non-announcement Days

	Employment Situation	Industrial Production	Petroleum Status	Natural Gas Storage	Announcement Days	Non-announcement Days
No. of observations	179	179	777	748	1638	2103
Crude Oil						
Mean	1.584	1.588	1.831	1.788	1.755	1.607
Median	1.309	1.183	1.447	1.361	1.359	1.206
Std. deviation	1.339	1.365	1.626	1.622	1.587	1.433
Minimum	0.037	0.014	0.003	0.003	0.003	0.000
Maximum	7.850	6.405	13.303	11.257	13.303	16.581
Heating Oil						
Mean	1.583	1.561	1.771	1.748	1.706	1.561
Median	1.321	1.176	1.464	1.344	1.336	1.204
Std. deviation	1.299	1.335	1.455	1.515	1.450	1.374
Minimum	0.028	0.071	0.004	0.000	0.000	0.001
Maximum	7.525	6.066	9.863	8.855	9.863	14.007
Natural Gas						
Mean	1.882	2.405	2.306	2.785	2.377	2.294
Median	1.568	1.756	1.801	2.254	1.865	1.741
Std. deviation	1.488	2.340	2.025	2.296	2.066	2.012
Minimum	0.035	0.005	0.003	0.088	0.003	0.001
Maximum	6.871	15.367	12.649	15.367	15.367	18.875

Note: Employment Situation, Industrial Production, Petroleum Status, and Natural Gas Storage are the days when the dummy variable for each report takes the value of one. Announcement Days are the days when at least one of the announcement dummy takes the value of one. Non-announcement Days are the days when none of the dummy variables takes the value of one.

Table 4. Summary Statistics of Change in Implied Volatility on Announcement and Non-announcement Days

	Employment Situation	Industrial Production	Petroleum Status	Natural Gas Storage	Announcement Days	Non-announcement Days
Crude Oil						
Mean	0.362	0.087	-0.407	-0.424	-0.311	0.367
Median	-0.140	0.028	-0.533	-0.680	-0.515	0.182
Std. deviation	3.687	5.221	4.493	4.432	4.309	4.352
Minimum	-5.900	-10.398	-18.649	-18.649	-18.649	-20.509
Maximum	19.018	40.748	40.748	40.748	40.748	35.294
Heating Oil						
Mean	0.279	0.229	-0.084	-0.332	-0.146	0.182
Median	0.000	0.000	0.000	0.000	0.000	0.028
Std. deviation	4.382	3.934	7.207	7.449	7.192	4.010
Minimum	-19.416	-7.714	-47.184	-158.425	-158.425	-28.271
Maximum	25.460	29.250	160.856	46.216	160.856	27.547
Natural Gas						
Mean	0.243	0.441	0.297	-0.905	-0.192	0.481
Median	-0.281	0.365	0.048	-1.270	-0.295	0.170
Std. deviation	3.128	4.361	4.175	4.582	4.067	4.104
Minimum	-7.035	-33.026	-19.959	-17.477	-33.026	-53.963
Maximum	15.864	18.779	49.427	49.427	49.427	42.957

Note: Employment Situation, Industrial Production, Petroleum Status, and Natural Gas Storage are the days when the dummy variable for each report takes the value of one. Announcement Days are the days when at least one of the announcement dummy takes the value of one. Non-announcement Days are the days when none of the dummy variables takes the value of one.

Table 5. Scheduled Announcements and Return Volatility

	Announcement Days	Non-announcement Days	Employment Situation	Industrial Production	Petroleum Status	Natural Gas Storage
Crude Oil						
Median(M)	1.359	1.206	1.308	1.183	1.447	1.361
KW statistic (H_0:M_{SA}=M_{NSA})	5.954**	NA	0.005	0.058	11.548***	4.809**
Mean (μ)	1.755	1.607	1.584	1.588	1.831	1.788
t-statistic (H_0:μ_{SA}=μ_{NSA})	2.951***	NA	-0.220	-0.180	3.387***	2.706***
Heating Oil						
Median(M)	1.336	1.204	1.320	1.176	1.464	1.344
KW statistic (H_0:M_{SA}=M_{NSA})	9.492***	NA	0.559	0.001	14.472***	6.488**
Mean (μ)	1.706	1.561	1.583	1.560	1.771	1.748
t-statistic (H_0:μ_{SA}=μ_{NSA})	3.087***	NA	0.211	-0.008	3.482***	2.968***
Natural Gas						
Median(M)	1.865	1.741	1.568	1.756	1.801	2.254
KW statistic (H_0:M_{SA}=M_{NSA})	1.567	NA	4.579**	0.005	0.024	28.423***
Mean (μ)	2.376	2.294	1.882	2.405	2.306	2.785
t-statistic (H_0:μ_{SA}=μ_{NSA})	-1.224	NA	-3.447***	0.614	0.144	5.182***

Note: The medians and means of the return volatility on the release days of each report are compared to non-announcement days. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Table 6. Scheduled Announcements and Change in Implied Volatility

	Announcement Days	Non-announcement Days	Employment Situation	Industrial Production	Petroleum Status	Natural Gas Storage
Crude Oil						
Median(M)	-0.515	0.181	-0.140	0.028	-0.533	-0.680
KW statistic (H_0:M_{SA}=M_{NSA})	43.235***	NA	1.196	1.940	30.759***	36.166***
Mean (μ)	-0.309	0.365	0.362	0.087	-0.407	-0.419
t-statistic (H_0:μ_{SA}=μ_{NSA})	-4.732***	NA	-0.010	-0.693	-4.133***	-4.184***
Heating Oil						
Median(M)	0.000	0.028	0.000	0.000	0.000	0.000
KW statistic (H_0:M_{SA}=M_{NSA})	10.772***	NA	0.358	1.062	9.351***	5.205**
Mean (μ)	-0.146	0.182	0.279	0.229	-0.084	-0.332
t-statistic (H_0:μ_{SA}=μ_{NSA})	-1.658*	NA	0.285	0.153	-0.979	-1.795*
Natural Gas						
Median(M)	-0.295	0.170	-0.281	0.365	0.048	-1.279
KW statistic (H_0:M_{SA}=M_{NSA})	49.835***	NA	3.925**	0.007	3.087*	138.322***
Mean (μ)	-0.194	0.482	0.243	0.441	0.297	-0.912
t-statistic (H_0:μ_{SA}=μ_{NSA})	-5.029***	NA	-0.956	-0.120	-1.061	-7.331***

Note: The medians and means of the change in implied volatility on the release day of each report are compared to non-announcement days. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Table 7. Parameter Estimates of Mean and Variance Equations for Return Volatility

	Crude Oil	Heating Oil	Natural Gas
Mean Equation			
Intercept (a)	1.242***	1.165***	1.753***
	(0.033)	(0.035)	(0.046)
Employment Situation (β_1)	0.062	0.085	-0.230*
	(0.091)	(0.085)	(0.125)
Industrial Production (β_2)	-0.061	-0.059	0.030
	(0.085)	(0.085)	(0.118)
Petroleum Status (β_3)	0.155***	0.173***	-0.084
	(0.045)	(0.044)	(0.068)
Natural Gas Storage (β_4)	0.090**	0.099**	0.418***
	(0.046)	(0.044)	(0.064)
$RV_{t-1}(b_1)$	0.033**	0.038**	0.007
	(0.015)	(0.015)	(0.015)
$RV_{t-2}(b_2)$	0.061***	0.089***	0.082***
	(0.015)	(0.014)	(0.015)
$RV_{t-3}(b_3)$	0.057***	0.074***	0.031**
	(0.015)	(0.015)	(0.015)
$RV_{t-4}(b_4)$	0.047***	0.054***	0.070***
	(0.015)	(0.015)	(0.015)
$RV_{t-5}(b_5)$	0.070***	0.092***	0.080***
	(0.015)	(0.015)	(0.014)
Variance Equation			
Constant (ω)	0.024***	0.010***	0.124***
	(0.007)	(0.004)	(0.032)
ARCH (γ)	0.027***	0.021***	0.043***
	(0.005)	(0.003)	(0.008)
GARCH (δ)	0.959***	0.972***	0.924***
	(0.007)	(0.005)	(0.013)

Note: Parameter estimates from AR (5)-GARCH (1, 1) model are presented with standard errors shown in parentheses. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Table 8. Parameter Estimates of Mean and Variance Equations for Change in Implied Volatility

	Crude Oil	Heating Oil	Natural Gas
Mean Equation			
Intercept (τ)	0.164**	0.020	0.277***
	(0.067)	(0.050)	(0.057)
Employment Situation (φ_1)	-0.346	-0.114	-0.499**
	(0.288)	(0.196)	(0.213)
Industrial Production (φ_2)	-0.259	-0.009	0.001
	(0.236)	(0.182)	(0.205)
Petroleum Status (φ_3)	-0.597***	-0.171*	0.100
	(0.138)	(0.096)	(0.107)
Natural Gas Storage (φ_4)	-0.709***	-0.091	-1.542***
	(0.142)	(0.099)	(0.104)
CIV_{t-1} (θ_1)	0.019	-0.015	0.035**
	(0.016)	(0.015)	(0.016)
CIV_{t-2} (θ_2)	-0.006	0.008	0.020
	(0.016)	(0.013)	(0.016)
CIV_{t-3} (θ_3)	-0.045***	-0.007	-0.023
	(0.016)	(0.012)	(0.015)
CIV_{t-4} (θ_4)	-0.035**	-0.009	0.003
	(0.015)	(0.010)	(0.015)
CIV_{t-5} (θ_5)	-0.000	-0.002	-0.003
	(0.015)	(0.009)	(0.014)
Variance Equation			
Constant (λ)	1.5658***	9.303***	2.575***
	(0.3060)	(1.201)	(0.419)
ARCH (π)	0.1340***	0.711***	0.210***
	(0.0198)	(0.043)	(0.031)
GARCH (ϑ)	0.7978***	0.277***	0.640**
	(0.0259)	(0.038)	(0.039)

Note: Parameter estimates from AR (5)-GARCH (1, 1) model are presented with standard errors shown in parentheses. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Table 9. Days-of-the-week Effect in Crude Oil Market

	Return Volatility			Change in Implied Volatility		
	All Days	Announcement Days	Non-announcement Days	All Days	Announcement Days	Non-announcement Days
Monday (M)	702	25	677	702	25	677
	1.711	2.536**	1.681	1.552	4.634*	1.438
Tuesday (T)	769	39	730	768	39	729
	1.570	1.089***	1.595	0.336	-0.008	0.355
Wednesday (W)	774	686	88	774	686	88
	1.836	1.862	1.639	-0.391	-0.521**	0.618
Thursday (R)	758	652	106	756	651	105
	1.708	1.718	1.651	-0.476	-0.444	-0.673
Friday (F)	738	236	502	736	236	500
	1.531	1.576	1.510	-0.576	0.103***	-0.897
F-statistic ($H_0: \mu_M=\mu_T=\mu_W=\mu_R=\mu_F$)	5.520***	5.190***	0.150	29.450***	1.760	5.010***
t-statistic ($H_0: \mu_M=\mu_{T-R}$, $H_1: \mu_M>\mu_{T-R}$)	0.085	2.395**	0.977	9.028***	2.990***	5.394***
t-statistic ($H_0: \mu_F=\mu_{T-R}$, $H_1: \mu_F<\mu_{T-R}$)	-2.964***	-1.955**	-1.304*	-2.309**	2.057	-5.006***

Note: Number of observations and mean values are reported. The announcement days columns test the equality of the means for this group to the means on non-announcement days. *, **, and *** denote statistical significance at the 10%, 5% and 1 % level of significance.

Table 10. Days-of-the-week Effect in Heating Oil Market

	Return Volatility			Change in Implied Volatility		
	All Days	Announcement Days	Non-announcement Days	All Days	Announcement Days	Non-announcement Days
Monday (M)	702	25	677	702	25	677
	1.701	2.312**	1.678	0.717	1.924	0.672
Tuesday (T)	769	39	730	767	39	728
	1.511	1.184**	1.528	0.069	-0.498	0.100
Wednesday (W)	774	686	88	771	683	88
	1.749	1.782*	1.496	-0.139	-0.135	-0.168
Thursday (R)	758	652	106	754	651	103
	1.667	1.681	1.583	-0.337	-0.367	-0.151
Friday (F)	738	236	502	736	236	500
	1.496	1.575	1.458	-0.069	0.271	-0.230
F-statistic (H_0:μ_M=μ_T=μ_W=μ_R=μ_F)	5.920***	2.350*	0.370	5.210***	3.220**	0.770
t-statistic (H_0:μ_M=μ_{T-R}, H_1:μ_M>μ_{T-R})	0.895	2.041**	2.013**	4.406***	2.895***	3.173***
t-statistic (H_0:μ_F=μ_{T-R}, H_1:μF<μ_{T-R})	-2.616****	-1.468*	-1.029	0.318	1.473	-1.210

Note: Number of observations and mean values are reported. The announcement days column tests the equality of the means for this group to the means on non-announcement days. *, **, and *** denote statistical significance at the 10%, 5% and 1 % level of significance.

Table 11. Days-of-the-week Effect in Natural Gas Market

	Return Volatility			Change in Implied Volatility		
	All Days	Announcement Days	Non-announcement Days	All Days	Announcement Days	Non-announcement Days
Monday (M)	702	25	677	702	25	677
	2.804	3.056	2.794	1.545	3.306	1.480
Tuesday (T)	769	39	730	769	39	730
	2.122	1.997	2.129	0.238	0.164	0.242
Wednesday (W)	774	686	88	773	685	88
	2.249	2.293**	1.907	0.302	0.373	-0.243
Thursday (R)	758	652	106	756	651	105
	2.592	2.649**	2.241	-1.121	-1.111	-1.180
Friday (F)	738	236	502	737	236	501
	1.912	1.855*	1.938	0.055	0.256	-0.039
F-statistic ($H_0: \mu_M=\mu_T=\mu_W=\mu_R=\mu_F$)	23.970***	0.890	4.580***	29.5300***	1.520	4.700***
t-statistic ($H_0: \mu_M=\mu_{T-R}$, $H_1: \mu_M>\mu_{T-R}$)	4.886***	1.043	6.145***	9.1042***	2.989***	6.636***
t-statistic ($H_0: \mu_F=\mu_{T-R}$, $H_1: \mu_F<\mu_{T-R}$)	-5.690***	-5.107***	-1.949**	1.6450	2.496	-0.367

Note: Number of observations and mean values are reported. The announcement days column tests the equality of the means for this group to the means on non-announcement days. *, **, and *** denote statistical significance at the 10%, 5% and 1 % level of significance.

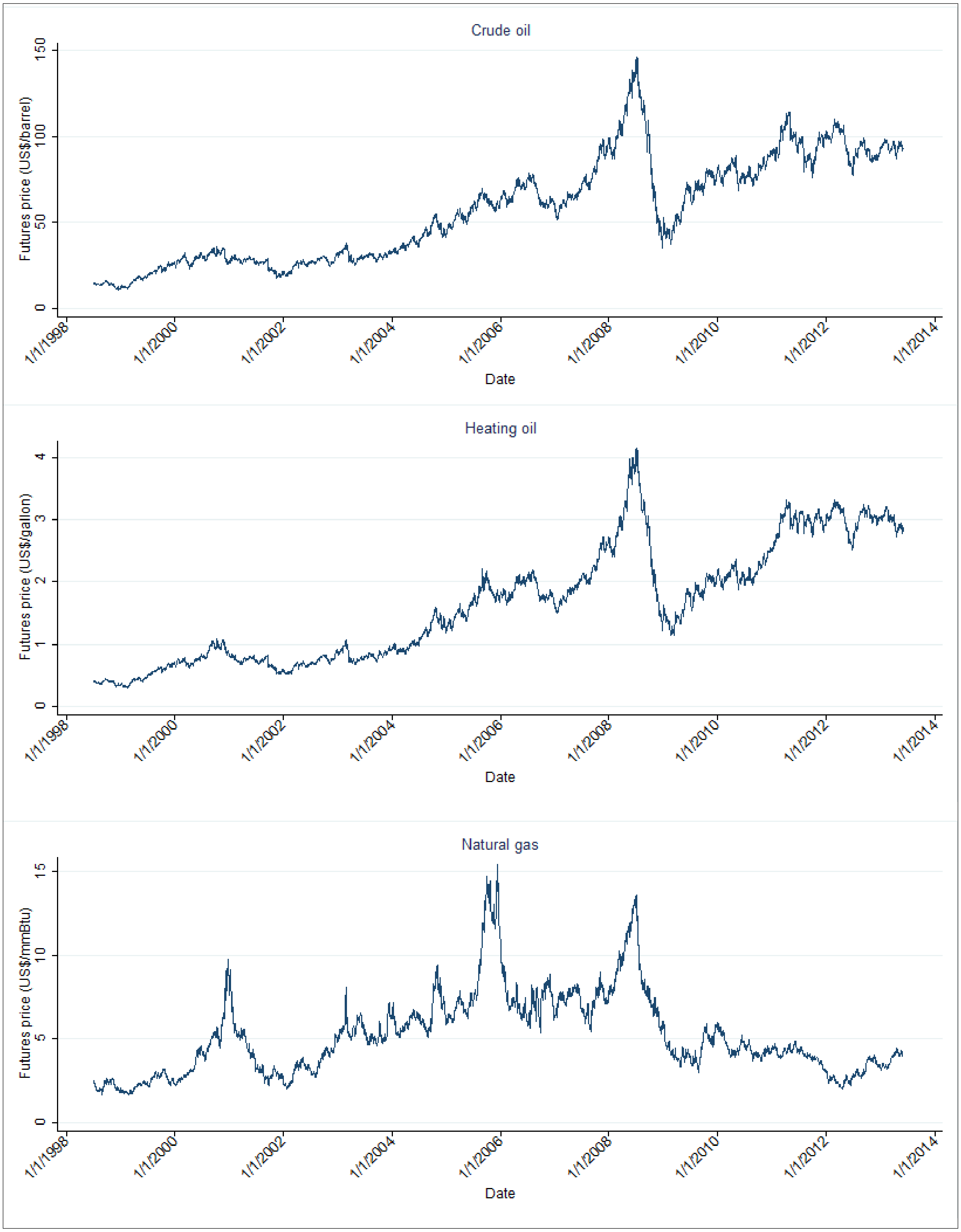

Figure 1. Energy futures prices, 1998-2013.

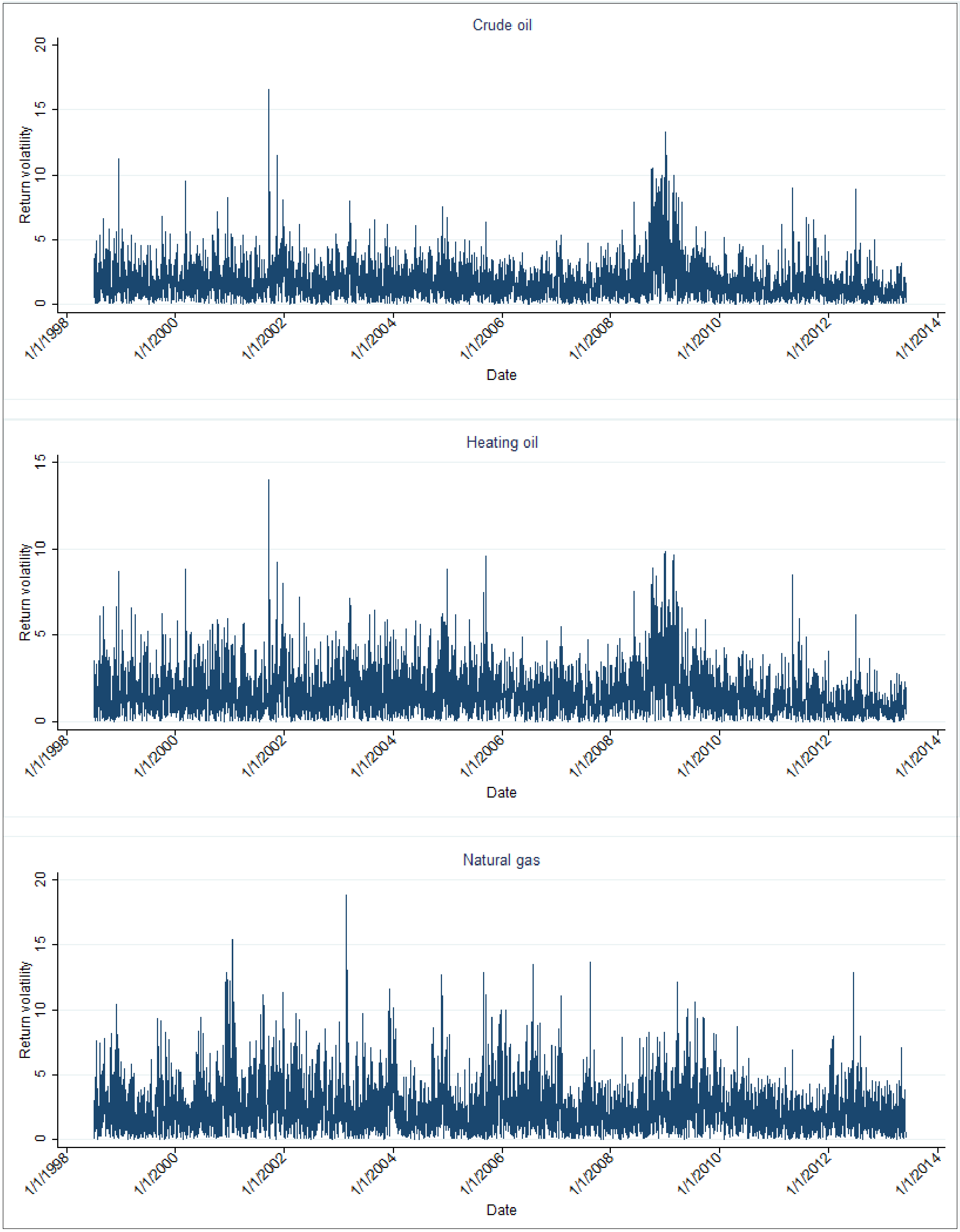

Figure 2. Return volatility of energy futures, 1998-2013.

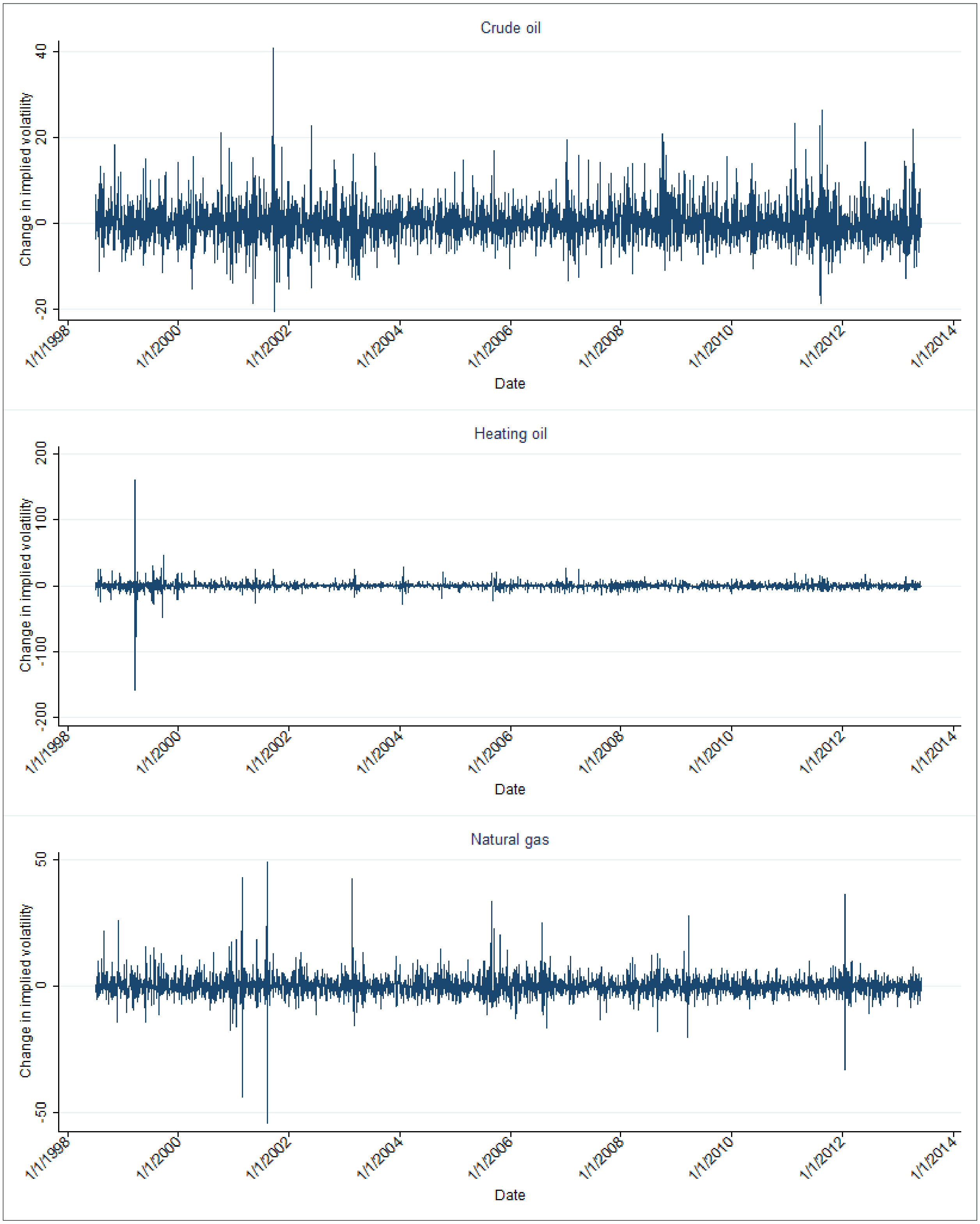

Figure 3. Change in implied volatility of energy options, 1998-2013.

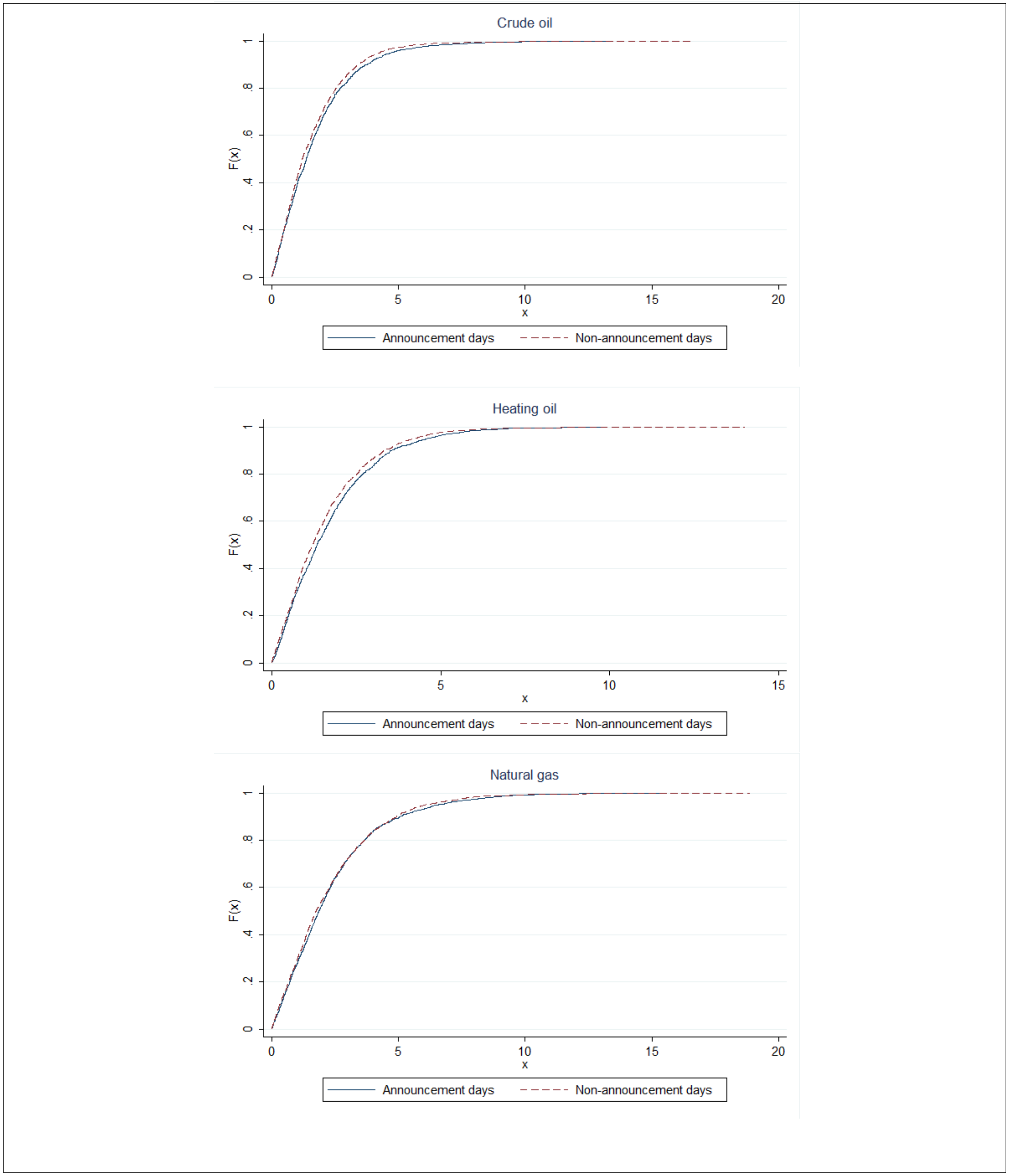

Figure 4. Cumulative distribution functions of the return volatility on announcement and non-announcement days.

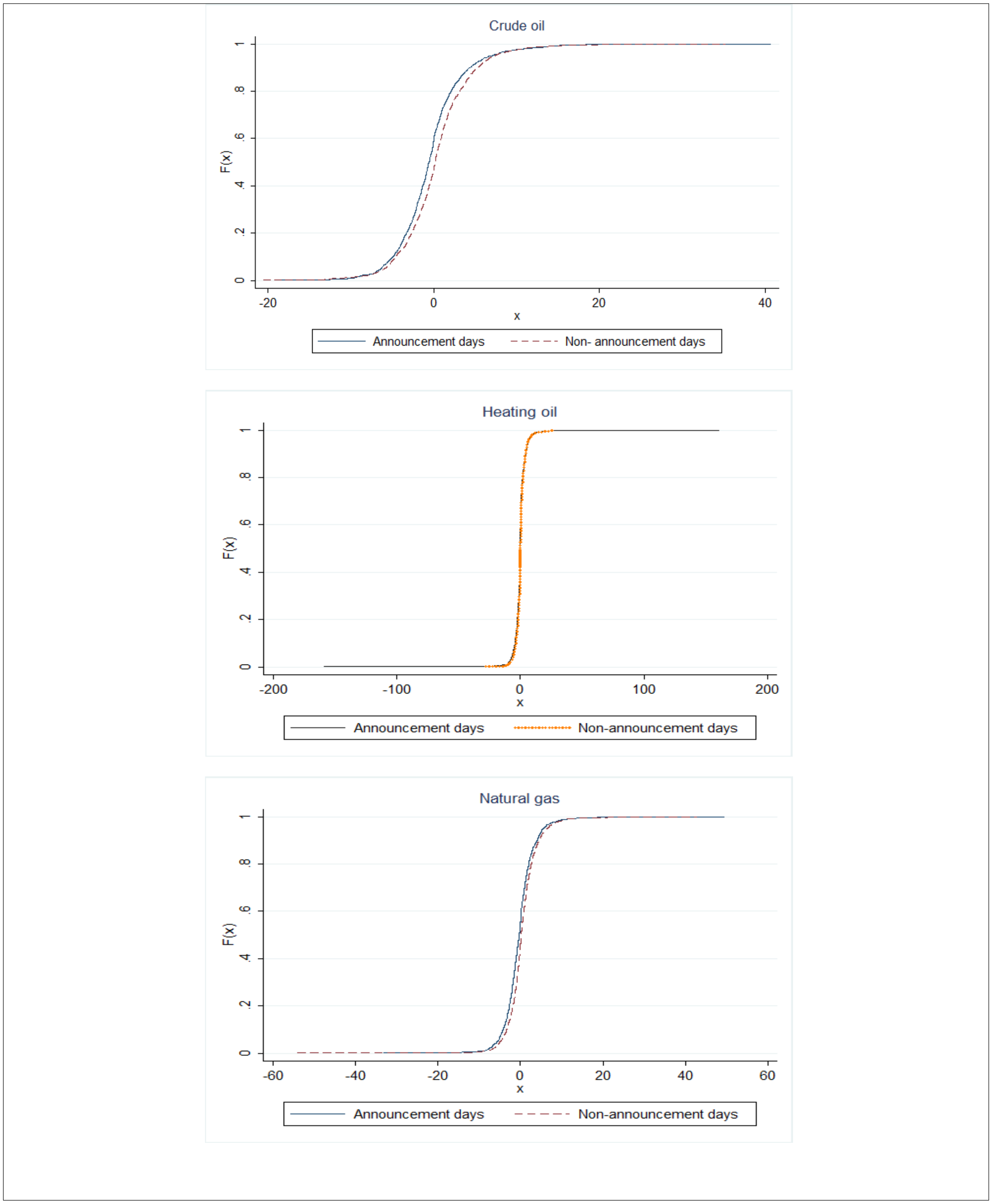

Figure 5. Cumulative distribution functions of the change in implied volatility on announcement and non-announcement days.

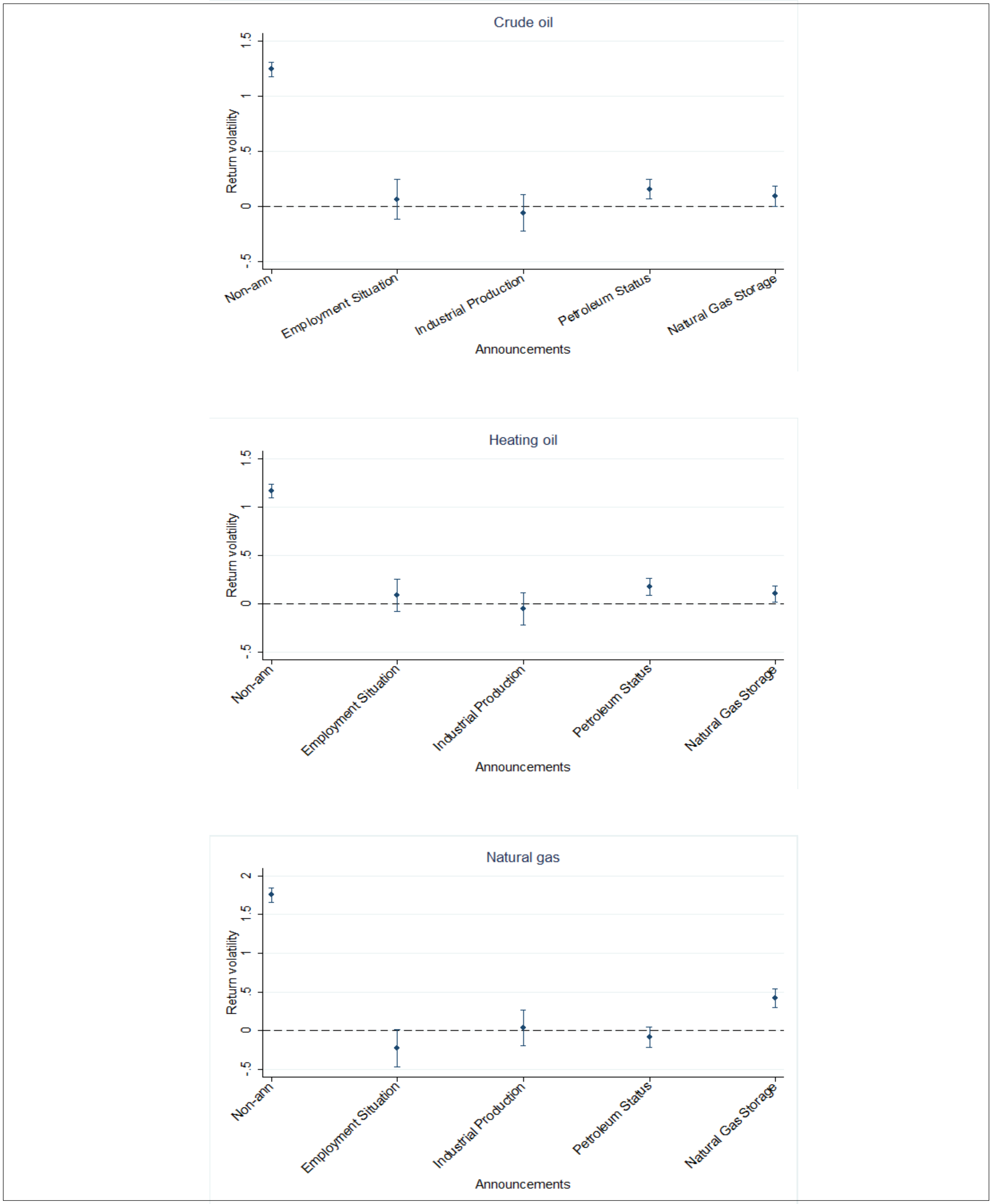

Figure 6. Point estimates and 95% confidence interval of each announcement's impact on return volatility.

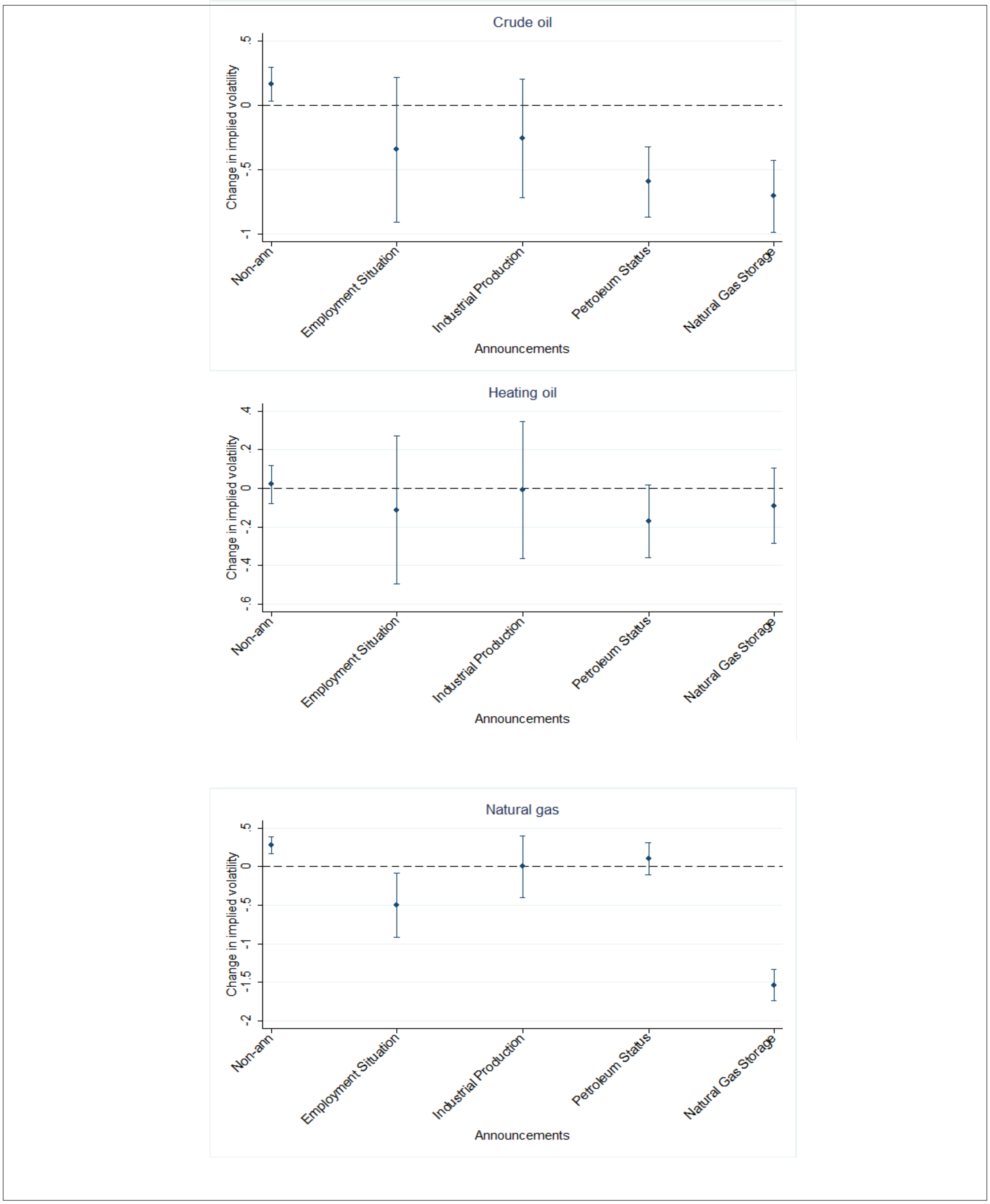

Figure 7. Point estimates and 95% confidence interval of each announcement's impact on change in implied volatility.