

Gas Does Affect Oil:  
Evidence from Intraday Prices and Inventory Announcements  
(JOB MARKET PAPER)

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**Abstract**

*Do events in the natural gas market cause repercussions in the crude oil market? In light of the enormous impact that price movements in the two largest U.S. energy markets have on the economy, it is important to understand not just the individual markets but also how they relate to one another. On this front, the literature presents a puzzle: while economic theory suggests that the oil and gas markets are interlinked through a bi-directional causal relationship, empirical research has concluded that the oil market affects the gas market but not vice versa. This paper improves on the previous studies in two ways: by using high-frequency, intraday oil and gas futures prices and by analyzing the effect of specific news announcements from the weekly oil and gas inventory reports. The results dispel the notion of one-way causality and provide support for the theory. The reaction of the futures volatility and returns is asymmetric, although this asymmetry does not follow the “good news” vs. “bad news” pattern from stock and bond markets; the response depends on whether the shock is driven by oil or gas inventory gluts or shortages. The two-way causality holds not only for the nearby futures contract but also for contracts of longer maturities. These findings underscore the importance of analyzing financial markets in a multi-market context.*

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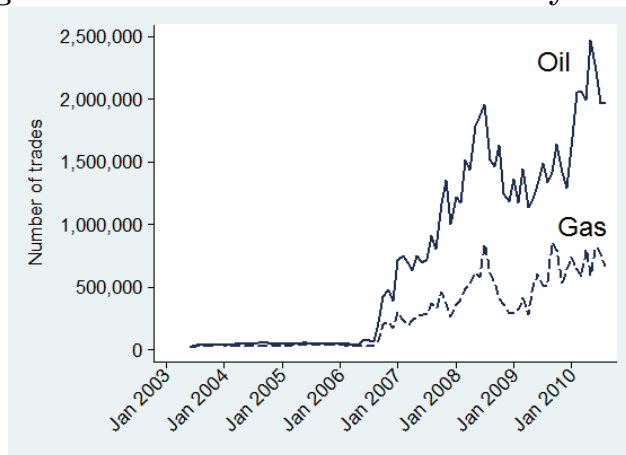
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# 1 Introduction

This paper studies the relationship between crude oil (referred to as “oil”) and natural gas (referred to as “gas”). It investigates whether there is two-way causality as suggested by economic theory or one-way causality as evidenced by previous empirical studies.

Price movements in markets for these two largest U.S. energy sources exert an enormous influence on the economy.<sup>1</sup> For example, Elder and Serletis (2010) show that oil price volatility has a negative effect on investment, durables consumption and aggregate output, and exacerbates the response of the economy to a negative oil price shock while dampening the response to a positive oil price shock. In addition, trading in the oil and gas futures markets has increased as shown by Figure 1, ranking the oil and gas futures as the first and the second largest energy futures, and the first and the ninth largest commodity futures by volume in 2008, respectively.<sup>2</sup> In light of this enormous impact of oil and gas on the macroeconomy as well as the financial markets, it is important to understand not just the markets for the individual commodities but also how they relate to one another.

**Figure 1: Number of futures trades by month**



*Notes: This figure shows the number of nearby futures trades executed on NYMEX by month.  
Source: Tick Data, Inc.*

On this front, the literature presents a puzzle. Economic theory suggests the existence of two-way causality between oil and gas markets for several reasons.<sup>3</sup> From the demand

<sup>1</sup>In 2009, oil and gas accounted for 37% and 25% of the energy use in the U.S. See the EIA Annual Energy Review 2009, Table 1.3.

<sup>2</sup>Futures Industry Magazine Annual Volume Survey: 2008 A Wild Ride.

<sup>3</sup>Villar and Joutz (2006) provide a summary of the economic theory.

perspective, oil and gas are substitutes because a portion of both the power generation and industrial sectors has the ability to switch between gas and products refined from crude oil as the production input. Therefore, an increasing oil price resulting from rising demand will increase the price of gas as some firms in these sectors switch from oil to gas. The relative price of oil and gas also influences decisions to build new facilities designed to consume a certain type of fuel. From the supply perspective, an increasing oil price resulting from increasing demand may lead to increased drilling and production of gas to substitute away from the more expensive oil, causing an increase in gas supply with a subsequent decrease in gas price. The gas price may also fall because gas is frequently found in the same underground reservoirs as oil, so an increasing oil demand satisfied by a higher production of oil may result in a higher production of gas, reducing the gas price. At the same time, however, the increasing oil price may intensify competition for resources, such as drilling rigs, production facilities, and engineering and operations staff used in exploration and production of both oil and gas, causing an increase in the gas price. In addition, the linkages between oil and gas prices should have strengthened because of the development of liquified natural gas technology (LNG), which allows the transportation of gas throughout the world and creates a world market for gas, a process that has accelerated since the 1990s.

However, the empirical research reviewed in Section 2 has concluded that the causality runs only in one direction: the oil market affects the gas market but not vice versa. Two explanations are usually stated. First, the oil market is larger than the gas market. Second, the oil market is global with prices determined by world supply and demand whereas the gas market is local with prices determined by local supply and demand. The first explanation does not seem satisfying since gas is almost as important an energy source as oil for the U.S. The second explanation also does not seem to hold because oil and gas are partial substitutes in the power generation and industrial sectors and the LNG technology has connected the local gas markets.

Since the conflict between theoretical and empirical research represents a puzzle with unsatisfying explanations, this paper investigates the contradiction. It improves on the previous studies in two ways. First, it uses high-frequency, *intraday* New York Mercantile Exchange (NYMEX) oil and gas futures prices, in contrast to observations taken at a lower

frequency, such as the daily, weekly or monthly data used by the previous papers, that do not capture price interdependencies accurately. Second, it analyzes the effect of *specific* news announcements from the weekly oil and gas inventory reports published by the Energy Information Administration (EIA) of the U.S. Department of Energy instead of conducting a general analysis of the relationship between the oil and gas prices using, for example, Granger causality tests as the previous studies. Even though these inventory reports are the most watched weekly indicators in the oil and gas markets, their effects have not been fully analyzed.<sup>4</sup>

Three results follow from this analysis. First, the notion of one-way causality is dispelled, providing support for the bi-directional causality indicated by the theory for the first time. Gas inventory announcements affect oil futures volatility and return, and oil inventory announcements affect gas futures volatility and return. These cross-commodity effects turn out to be substantial. The effect of *gas* inventory announcements on *oil* price volatility is more than twice as strong as the effect of *oil* inventory announcements on *gas* price volatility, highlighting the importance of spillovers from the gas market to the oil market.

Second, the model allows for different reactions of price volatility and return to inventory gluts and shortages.<sup>5</sup> However, in contrast to the “good news” vs. “bad news” pattern found in stock and bond markets, the response differs by commodity and type of the shock. A glut has a larger impact than a shortage for the effect of *oil* inventory announcements on *oil* price volatility. In contrast, a glut has a slightly smaller impact than a shortage for the effect of *gas* inventory announcements on *oil* price volatility, which is also the case for the effect of *gas* inventory announcements on *gas* price volatility. Finally, a glut has the same effect as a shortage for the effect of *oil* inventory announcements on *gas* price volatility. This highlights the importance of analyzing the data in detail since a general analysis is unable to uncover these differences.

Third, in contrast to previous studies that analyzed only the nearby futures contract for the following month, this paper includes contracts with all maturities to investigate how

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<sup>4</sup>For example, the Financial Times noted as of September 21, 2011: “The U.S. is the world’s largest oil consumer and its weekly petroleum status reports are closely watched.”

<sup>5</sup>Except for Gregoire and Boucher (2008), who analyze the effect of *gas* inventory announcements on *gas* price using daily data, previous papers have not analyzed the asymmetry between inventory gluts and shortages.

current news announcements affect financial instruments at various points in the future. The two-way causality indicated by the cross-commodity effect holds not only for the nearby contract but also for the following seven months' contracts. The asymmetry effect also persists across these maturities. The results described above are, therefore, robust to the maturity structure. In general, the coefficients decrease as the length of the contract increases, supporting the Samuelson (1965) theorem that futures contracts become more volatile as their expiration date approaches.

In addition to our validating the economic theories on the two largest U.S. energy markets, identifying precise linkages between these markets is important for several other reasons. Numerous studies have highlighted the importance of volatility spillovers between the oil market and financial markets, e.g., stock markets and exchange rate markets, a topic of interest to regulators and policy-makers.<sup>6</sup> To fully understand these spillovers, it is important to realize that the oil volatility partially originates in another energy market, i.e., the gas market.

Also, as documented by Buyuksahin, Haigh, Harris, Overdahl and Robe (2008) and Basu and Gavin (2011), the recent dramatic rise in oil and gas futures trading evidenced by Figure 1 is mainly due to an increasing number of financial institutions participating in commodity derivatives such as oil and gas futures. According to Buyuksahin et al (2008), the share of traditional commercial traders, such as oil and gas exploration, production, and refining companies who use the futures for commercial hedging decreased from 83% in 2000 to 55% in 2008. At the same time, according to Basu and Gavin (2011), non-commercial financial traders, such as investment banks, mutual funds, pension funds, university endowment funds and hedge funds, increased their investments in commodity derivatives, in an attempt to diversify their stock market risk and chase higher yield, higher risk investments. Since financial institutions played a key role in the recent economic crisis by investing in complex financial products such as derivatives, and had to be bailed out by the taxpayers, it is imperative to understand the markets in which they have an increasing exposure.<sup>7</sup>

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<sup>6</sup>See, for example, Kilian and Park (2009), Cifarelli and Paladino (2010), and Hammoudeh, Yuan and McAleer (2010).

<sup>7</sup>Trading in oil and gas options based on oil and gas futures has also been on the rise, with financial institutions again becoming more dominant market players. Since the correct pricing of options relies on the ability to reliably estimate volatility of the underlying asset, i.e., that of the futures contract, it is again

Finally, this paper contributes to the discussion of whether oil prices are exogenous or endogenous to the macroeconomy. While earlier papers, e.g., Hamilton (1985), attribute oil price changes to exogenous events, such as political instability producing disruptions in oil supply, more recent studies, e.g., Barsky and Kilian (2002, 2004) and Kilian (2009), have challenged this view by showing that oil price changes can endogenously follow from demand changes.<sup>8</sup> This paper provides another piece of evidence that oil prices evolve in a bi-directional causal relationship instead of being exogenous. This improved understanding of the linkages between the oil and gas markets may provide insight into modeling dependencies of the macroeconomy on the energy markets. Krichene (2007) develops a model for analyzing the oil and gas markets with a role for monetary policy. However, in his simultaneous equations, the gas demand and supply are affected by oil but the oil demand and supply are not affected by gas. Such a misspecification may lead to misguided policies. These considerations underscore the importance of analyzing energy (and financial) markets in a multi-market context.

## 2 Literature Review

Although theory suggests a two-way relationship between the oil and gas markets, the empirical research by Pindyck (2004), Villar and Joutz (2006), Asche, Osmundsen and Sandsmark (2007), Brown and Yucel (2007) building on an earlier paper by Brown (2005), and Hartley, Medlock and Rosthal (2008) concluded that the causality runs only in one direction: the oil market affects the gas market but not vice versa.<sup>9</sup> Onour (2009) also noted that the gas price is affected by the oil price, especially at low oil prices (below \$40 per barrel), but did not investigate the sensitivity of oil to gas. See Table 9 in Appendix A for an overview of

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critical to understand how the volatility is partially driven by spillovers from another market.

<sup>8</sup>Hamilton (2008) and Kilian (2008) provide literature reviews of the relationship between oil prices and the macroeconomy.

<sup>9</sup>Pindyck (2004) conducted Granger causality tests using the conditional volatility from GARCH models. When estimating the GARCH model with daily data, he concluded that the oil market affected the gas market but not the other way around which he said was the expected result. When estimating the GARCH model with weekly data, he obtained the opposite result but disregarded it, arguing that correlations between the oil and gas volatilities are low in the weekly model.

the data used in these papers.<sup>10</sup>

While the above papers claim that the gas market does not affect the oil market, this study uncovers evidence of such a relationship. It differs from the previous empirical papers in two respects. First, it takes advantage of NYMEX *intraday* oil and gas futures prices, i.e., prices at a higher frequency than the daily, weekly or monthly prices used by the previous papers. Second, in contrast to the previous papers that conduct a general analysis of the relationship between the oil and gas prices using, for example, Granger causality tests, this paper analyzes the effect of specific news announcements: the weekly oil and gas inventory reports published by the EIA.

Four papers have analyzed the effect of inventory announcements on intraday energy prices. Linn and Zhu (2004) studied the effect of *gas* inventory announcements on intraday *gas* futures price return and volatility from 1999 through 2002 and concluded that volatility increased after inventory announcements. However, they included only the actual inventory level. This is an issue because the efficient market theory states that only the unanticipated component of news announcements matters because the anticipated component has been built into price forecasts by rational economic agents. Therefore, the correct methodology for analyzing the impact of news announcements on prices requires that market expectations be subtracted from the actual value to arrive at the unanticipated component.

Gay, Simkins and Turac (2009) investigated whether investors learned about analyst accuracy using *gas* inventory announcements and *gas* futures prices from 1997 through 2005. Focusing only on futures return and disregarding price volatility, they concluded that the oil futures return reacted to analyst forecasts.

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<sup>10</sup>Several other papers have studied the relationship between oil and gas markets without analyzing causality. Yucel and Guo (1994) showed that oil, gas and coal prices were cointegrated from 1974 through 1990 although only oil and coal prices were cointegrated from 1947 through 1974. Panagiotidis and Rutledge (2007) also found a cointegrating relationship between oil and gas prices, while Serletis and Rangel-Ruiz (2004) reported that the oil and gas relationship had weakened and Bachmeier and Griffin (2006) concluded that the oil, gas and coal markets were only very weakly integrated. Wang, Wu and Yang (2008) showed that the correlation between oil and gas prices did not exhibit long-memory, implying a weak relationship in the long run. Marzo and Zagaglia (2008) noted that the correlation between the oil and gas prices has been rising since 2000 although this correlation was low on average over two thirds of the sample period. See Table 10 in Appendix A for an overview of the data used in these papers. Also, related papers studied relationships between other commodities. Serletis and Herbert (1999) focused on daily gas, fuel oil, and power prices from 1996 through 1997, while Ohana (2010) analyzed daily spot gas and heating oil futures prices from 2000 through 2009.

Bjursell, Gentle and Wang (2009) considered, among other things, the effect of *oil* inventory announcements on *oil* intraday volatility and the effect of *gas* inventory announcements on *gas* intraday volatility. Instead of subtracting the market expectations from the actual values to arrive at the unexpected component, they estimated the “surprise” based on historical inventory levels. They concluded that this ”surprise” increased volatility in gas and heating oil prices.

Chang, Daouk and Wang (2009) investigated whether investors learn about analyst accuracy using *oil* inventory announcements and *oil* futures prices from 2003 through 2005. Focusing only on price return and disregarding price volatility, they concluded that the oil price return rises (falls) when analysts forecast a decrease (increase) in supplies.<sup>11</sup>

None of these four papers on the effect of inventory announcements focused on the cross-commodity effect, i.e., the effect of *gas* inventory announcements on the *oil* price and the effect of *oil* inventory announcements on the *gas* price. Also, these papers did not distinguish between positive and negative surprises, which prevented them from discussing asymmetries between effects of inventory shortages and gluts. Finally, they focused only on the nearby futures contract, ignoring the effect on contracts with longer maturities.<sup>12</sup>

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<sup>11</sup>Three of the above papers on the causal relationships between the oil and gas markets allowed inventory to play a limited role. Villar and Joutz (2006), Brown and Yucel (2007), and Hartley, Medlock and Rosthal (2008) included the gas inventory but ignored the oil inventory. More importantly, they included only the actual inventory, i.e., they failed to subtract market expectations of the inventory.

<sup>12</sup>Seven papers have analyzed the effect of other news announcements on oil prices. Ghura (1990) focused on the impact of five U.S. macroeconomic announcements, exchange rates and interest rates on price returns of oil and nineteen other commodities using daily prices from 1985 through 1989. Kilian and Vega (2008) conducted a more comprehensive study by analyzing the impact of thirty U.S. macroeconomic announcements on price returns of oil and gasoline using daily data from 1983 through 2008. Roache and Rossi (2009) analyzed the impact of thirteen U.S. and European announcements on price returns and volatilities of oil and eleven other commodities using daily data from 1997 through 2009. Guidi, Russell and Tarbert (2006), Schmidbauer and Rosch (2009), and Lin and Tamvakis (2010) studied the effect of OPEC decisions while Leinert (2010) considered the effect of unanticipated discoveries of giant oil fields. Three papers analyzed the effect of other announcements on gas prices: Ates and Wang (2007), Mu (2007), and Gregoire and Boucher (2008).

## 3 Data

### 3.1 Oil and Gas Futures Prices

Oil and gas futures contracts are traded on two main exchanges: the NYMEX in Chicago and the InterContinental Exchange (ICE) in London. This paper focuses on the NYMEX futures data because NYMEX is more liquid than ICE.<sup>13</sup> This proprietary data is provided by Tick Data, Inc., a company that specializes in intraday time series data for equities, futures and options.<sup>14</sup> The data are transaction data, i.e., not bid-ask quotes.

Light Sweet Crude Oil futures started trading on NYMEX under the symbol CL on March 30, 1987. Currently, the trading day takes place on Mondays through Fridays from 9:00 a.m. till 2:30 p.m. Eastern Time.<sup>15</sup> The standardized contract is for 1,000 barrels with the price quoted in U.S. dollars per barrel. Futures contracts with different maturities are available. The shortest maturity, called the nearby contract, is for the following month. The longest maturity is nine years. Trading ceases on the third business day prior to the twenty-fifth calendar day of the month preceding the delivery. At expiration, oil has to be physically delivered to Cushing, OK.<sup>16</sup> Figure 2 presents the oil nearby contract price from 2003 to 2010.

Natural gas futures started trading on NYMEX under the symbol NG on January 4, 1993. The trading hours are identical to those for oil. The standardized contract is for 10,000 million British thermal units (mmBTU) with the price quoted in U.S. dollars per mmBTU. Maturities from one month to twelve years are available. Trading ceases three business days prior to the first day of the delivery month. At expiration, gas has to be physically delivered to Henry Hub, LA. Figure 3 presents the gas nearby contract price from 2003 to 2010.

Very few market participants choose to make physical delivery at contract expiration. Instead, they roll over their positions into a new contract. Two methodologies are used in this paper to create a continuous record of the futures contract prices. In the first methodology,

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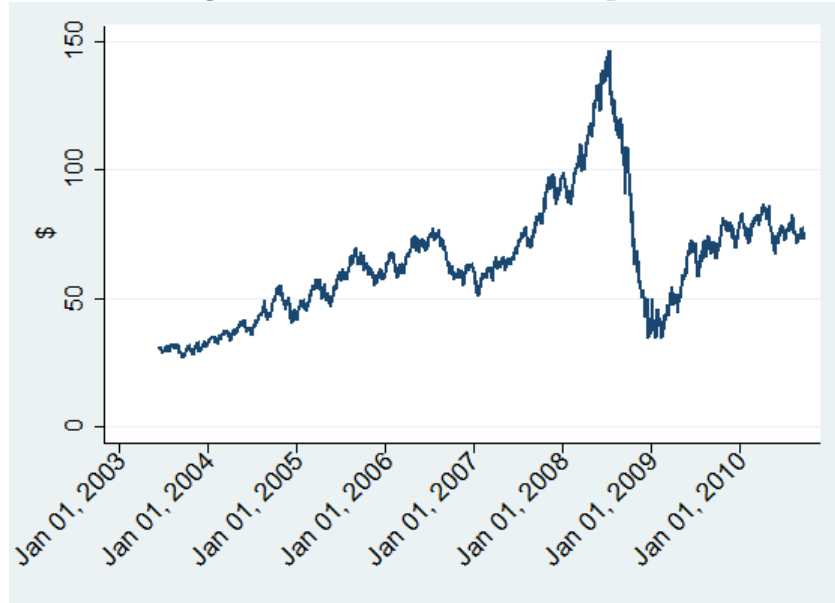
<sup>13</sup>See Downey (2009) for description of the oil market.

<sup>14</sup>See [www.tickdata.com](http://www.tickdata.com).

<sup>15</sup>Until January 31, 2007, the trading day started at 10:00 a.m. Night trading is not analyzed in this paper since the day and night trading sessions may differ from the information arrival standpoint.

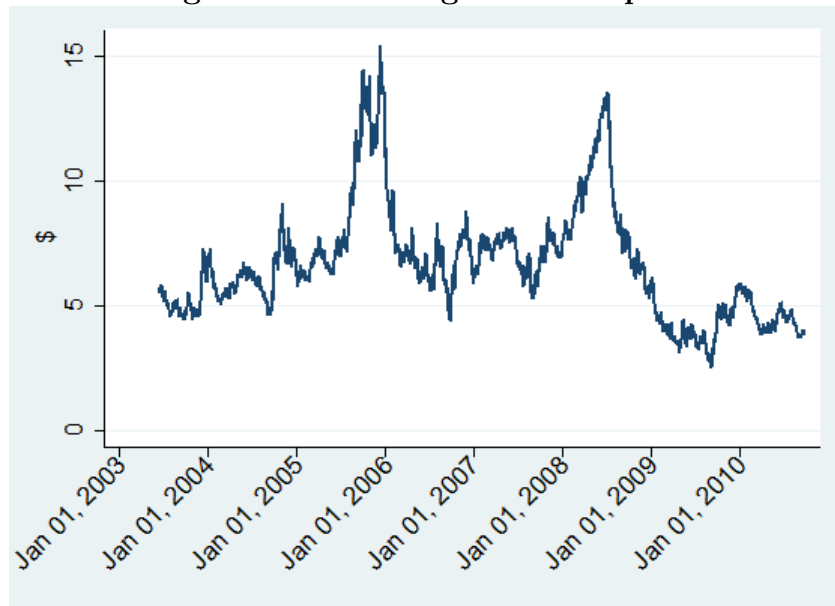
<sup>16</sup>See website of CME Group that owns NYMEX: [www.cmegroup.com](http://www.cmegroup.com).

**Figure 2: Crude oil futures price**



*Notes: This figure shows the price of the NYMEX crude oil nearby futures contract per barrel in U.S. dollars.  
Source: Tick Data, Inc.*

**Figure 3: Natural gas futures price**



*Notes: This figure shows the price of the NYMEX natural gas nearby futures contract per million British thermal units in U.S. dollars.  
Source: Tick Data, Inc.*

the current contract is used until the expiration date. However, as market participants begin rolling over their positions on the preceding days, trading may be thin during the last days before the contract expiration date, causing unusual price movements. Therefore, the second

methodology switches to the next contract as soon as its daily contract volume exceeds the current contract volume. The results do not materially differ between the two methods. Therefore, only results using the expiration date method are reported.<sup>17</sup>

### **3.2 Weekly Petroleum Status Report**

The data on the U.S. oil inventory come from the Weekly Petroleum Status Report published by the EIA. This report is prepared by the EIA based on companies submitting weekly forms stating their current oil inventory, as mandated by law.<sup>18</sup> The first report was published on August 20, 1982. The report is released weekly on Wednesday at 10:30 am for the week ending on the previous Friday. If Monday, Tuesday or Wednesday fall on a public holiday, the report is released on the following Thursday at 11:00 am.<sup>19</sup> See Appendix B for a discussion of the adjustment to holidays. Only commercial inventory is considered in this paper, i.e., the Strategic Petroleum Reserves held by the U.S. government are excluded. The data are in thousands of barrels.

### **3.3 Weekly Natural Gas Storage Report**

The data on the gas inventory in the the U.S. Lower 48 states come from the Weekly Natural Gas Report published by the EIA based on companies submitting weekly forms stating their current gas inventory, as mandated by law.<sup>20</sup> The first report was published on December 31, 1993. The report is released weekly on Thursday at 10:30 am for the week ending on the previous Friday unless Thursday falls on a public holiday. There are twelve such holiday weeks in the sample period. It is assumed that the report was released at 10:30 am on the following Friday during these holiday weeks.<sup>21</sup> See Appendix B for a discussion of the

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<sup>17</sup>Another method chooses a particular date, e.g., the 15th calendar day of each month to switch from the nearby contract to the second nearby contract in an attempt to model the market participants' behavior. This approach is not used in this paper because it is arbitrary.

<sup>18</sup>See [www.eia.doe.gov](http://www.eia.doe.gov).

<sup>19</sup>These holiday weeks are skewing the intraday pattern graphs in Sections 5.1.1 and 5.2.1. The regressions are correct because the data show the inventory reports on the days and intervals when they are actually released. As a robustness check, however, these weeks are eliminated from the data. The results do not change materially. The results reported in this paper include the holiday weeks.

<sup>20</sup>See [www.eia.doe.gov](http://www.eia.doe.gov).

<sup>21</sup>The American Gas Association (AGA) published this report prior to the end of April of 2002. The AGA released the report on Wednesdays after NYMEX market closing time from December 31, 1993 until

adjustment to holidays. The data are in billions of cubic feet.

### 3.4 Expectations of the Weekly Petroleum Status Report

Bloomberg conducts a weekly survey of approximately twenty industry experts asking them what they expect the oil inventory excluding the Strategic Petroleum Reserves to be once released by the EIA, and publishes the minimum, maximum, mean and median values of the expert forecasts (in thousands of barrels). This paper uses the median forecast.<sup>22</sup> The survey is published on Monday or Tuesday, i.e., prior to the actual values being released by the EIA. The first survey was conducted on June 13, 2003.<sup>23</sup> As explained in Section 4, the “surprise” is calculated as the difference between the EIA inventory announcement and the Bloomberg survey forecast.

### 3.5 Expectations of the Weekly Natural Gas Storage Report

Bloomberg conducts a weekly survey of approximately twenty-five industry experts asking them what they expect the gas inventory to be once released by the EIA (in billions of cubic feet), using the same methodology as for oil. The first survey was conducted on May 3, 2002.

## 4 Methodology

Deciding on the length of the intraday time interval involves choosing between noise due to the data microstructure and loss of information. Using the volatility signature plot that shows the scaled realized volatility, i.e., daily average of squared returns, against time intervals in multiples of one minute as outlined by Andersen, Bollerslev, Diebold and Labys (2000), the 10-minute interval is chosen as the appropriate length. See Appendix C for

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February 25, 2000 and between 2:00 pm and 2:15 pm from March 3, 2000 until April 26, 2002. The EIA took over on May 3, 2002. However, as this study is limited to the period from June 13, 2003 until September 24, 2010, it is not affected by the change of the release day from Wednesday to Thursday.

<sup>22</sup>The data can be found on the Bloomberg terminal under the code ECO with “North America” under Region, “U.S.” under Country, and “10) Energy/Commodities” under Type. The list of economists surveyed, including the date of the survey, can be obtained by typing in “12”.

<sup>23</sup>Note that Bloomberg asks the experts by how much they expect the inventory to change compared with the previous week. Therefore, to arrive at the expected inventory, it is necessary to add the previous week’s actual inventory and the experts’ expectation of the change in inventory.

volatility signature plots for oil and gas prices.<sup>24</sup> For example, the first 10-minute interval contains trades from 9:00:00 till 9:09:59.<sup>25</sup> There are 27 and 33 intervals within a trading day depending on whether the market opens at 10 a.m. or 9 a.m. The days when the NYMEX market closes earlier, usually due to an upcoming holiday, are eliminated to prevent skewing intraday patterns.<sup>26</sup> Missing prices are set equal to the previous prices.<sup>27</sup> The resulting sample period contains 54,884 10-minute intervals on 1,826 days from June 13, 2003 until September 24, 2010, a period of 380 weeks.

Let  $P_j$  be the price at the end of 10-minute interval  $j$ . Since both oil and gas price series are non-stationary, the return, i.e., the difference between the log price at the end of interval  $j$  and the log price at the end of interval  $j-1$ ,  $R_j \equiv \ln(P_j) - \ln(P_{j-1})$ , is used. The resulting return series is stationary as gauged by an augmented Dickey-Fuller test.

This paper analyzes the effect of announcements on price returns as well as volatility, defined as the absolute value of the returns,  $|R_j|$ , following, for example, Ding, Granger and Engle (1993), Ederington and Lee (1993), Gwilym, McMillan and Speight (1999), McKenzie (1999), Bollerslev, Cai and Song (2000), and Ederington and Guan (2005). See Figures 4 and 5 for oil and gas absolute price returns, respectively.

The methodology for analyzing the effect of news announcements on prices assumes efficient markets, implying that only the unanticipated component of news announcements matters because the anticipated component has been built into market participants' price forecasts. The unexpected component is the difference between the actual value,  $A_{kj}$ , and the expected value,  $E_{kj}$ , where  $k \in \{O, G\}$  stands for oil and gas announcements. Since this difference is in thousands of barrels and billions of cubic feet for oil and gas, respectively, it is divided by the actual value and then multiplied by 100. The resulting "surprise",  $S_{kj} \equiv \frac{A_{kj} - E_{kj}}{A_{kj}} \times 100$ , can then be interpreted as a percentage deviation of the expectations from the actual values.<sup>28</sup> Statistics for the oil inventory surprise,  $S_O$ , and the gas inventory

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<sup>24</sup>See Dacorogna, Gencay, Muller, Olsen and Pictet (2001) for a discussion of scaling factors. Also, note that the realized volatility is used only to choose the appropriate interval. It is not used in the regressions. The dependent variable in the volatility regressions is defined as the absolute return.

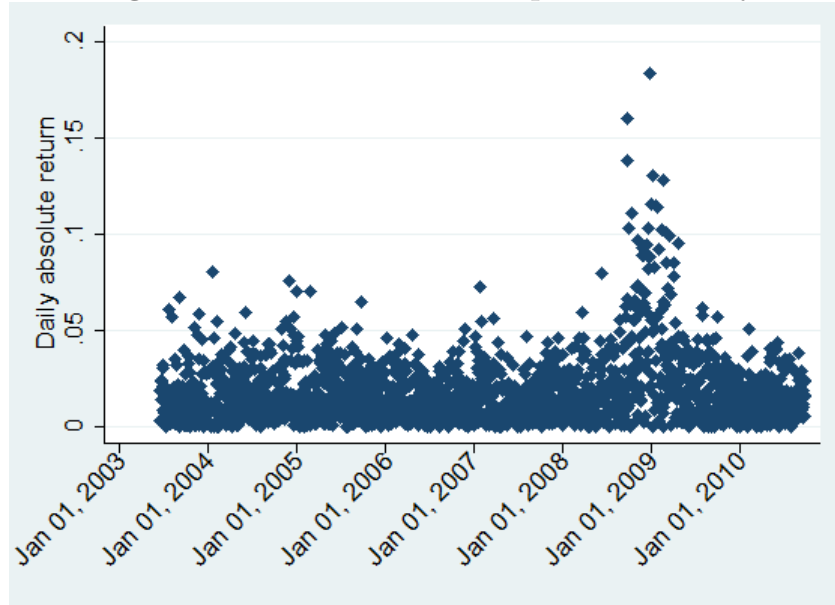
<sup>25</sup>As a robustness check, the analysis is repeated using 15-minute and 30-minute intervals. The results do not change materially.

<sup>26</sup>There are only 20 such days within the sample period.

<sup>27</sup>There are very few such missing observations (0.20% and 0.45% of all observations for the oil and gas nearby contracts, respectively).

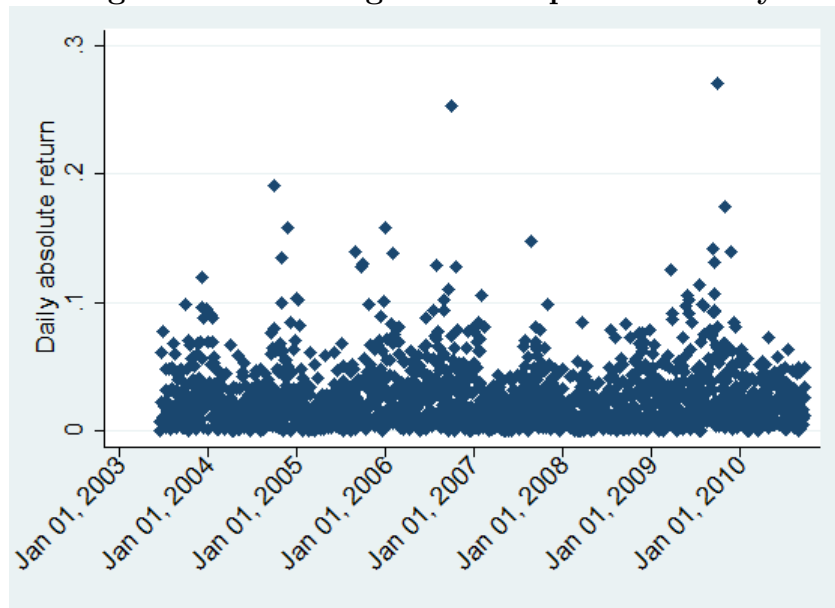
<sup>28</sup>Balduzzi, Elton and Green (2001) implement another methodology for standardizing announcement

**Figure 4: Crude oil futures price volatility**



*Notes: This figure shows the price volatility of the NYMEX crude oil nearby futures contract defined as absolute return.  
Source: Tick Data, Inc.*

**Figure 5: Natural gas futures price volatility**



*Notes: This figure shows the price volatility of the NYMEX natural gas nearby futures contract defined as absolute return.  
Source: Tick Data, Inc.*

surprise,  $S_G$ , are summarized in Table 1. Since the mean values of these variables are units. They divide the difference between the actual and expected values by its sample standard deviation  $\sigma_k$  and interpret the coefficient as the change in oil price return for one standard deviation change in the surprise. In this paper, dividing by the actual value is preferred to allow for interpreting the surprise as a percentage deviation of the expectation from the actual value.

close to zero, the Bloomberg survey can be considered unbiased, i.e., the analysts do not systematically overforecast or underforecast.

**Table 1: Summary statistics for oil and gas inventory surprise variables**

	Min	Max	Mean	Standard Deviation
Oil inventory surprise, $S_O$	-2.85%	2.82%	-.02%	.94%
Gas inventory surprise, $S_G$	-1.55%	2.93%	.05%	.46%

A positive surprise,  $S_{kj} > 0$ , i.e.,  $A_{kj} > E_{kj}$ , means that the actual inventory, when announced by the EIA, is higher than what the analysts expected. In other words, the analysts underforecast the actual inventory resulting in an inventory glut. A negative surprise,  $S_{kj} < 0$ , i.e.,  $A_{kj} < E_{kj}$ , means that the actual inventory, when announced by the EIA, is lower than what the analysts expected. In other words, the analysts overforecast the actual inventory, resulting in an inventory shortage.

To allow for the possibility of asymmetric reaction of the price return and volatility to shortages and gluts, indicators,  $I(S_{kj} > 0)$ , are created for oil and gas that take on value of 1 if  $S_{kj} > 0$  and 0 otherwise. These indicators are then multiplied by the surprise, i.e.,  $S_{kj} \times I(S_{kj} > 0)$ . This allows interpreting the coefficient on the surprise,  $S_{kj}$ , as the effect of a shortage. The sum of the coefficients on  $S_{kj}$  and  $S_{kj} \times I(S_{kj} > 0)$  can then be interpreted as the effect of a glut.

The effect of the announcements is analyzed using ordinary least squares (OLS) regression. Several control variables are included in the regressions in addition to the above surprise variables. As suggested by Andersen, Bollerslev, Diebold and Vega (2003), lags of surprise and dependent variable are added to allow for autocorrelation.<sup>29</sup>

A beginning-of-day dummy is included to account for unusual price movements at the beginning of the day and to account for the change in the beginning of the trading day from 10:00 to 9:00 on February 1, 2007. This dummy takes on the value of 1 during the first interval of the day and 0 in all other intervals. An end-of-day dummy is included in the same

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<sup>29</sup>33 lags are used since a trading day includes 33 10-minute intervals. In an alternative specification, the model is modified to include lagged cross-commodity terms, i.e., the *oil* price volatility (return) equations include *gas* price volatility (return) lags. The results do not change.

way to account for unusual price movements at the end of the day. These time-of-the-day effects have been identified in many financial markets, for example by Becker, Finnerty and Kopecky (1993), Gwilym, McMillan and Speight (1999), Bollerslev, Cai and Song (2000), and Linn and Zhu (2004).<sup>30</sup> A first-trading-day dummy is included that takes on the value of 1 in all intervals on the day after a non-trading day, i.e., after a weekend or a holiday, to allow for effects due to the market being closed for an extended period of time. A trader composition variable, defined as the ratio of non-commercial financial traders volume to the traditional commercial traders volume, is added to account for a change in the composition of firms trading oil futures, as documented by Buyuksahin et al (2008). These authors show that the proportion of non-commercial financial traders has been on the rise and the proportion of traditional commercial traders has declined. The three-month Treasury bill rate is included because Pindyck (2004) shows that this interest rate helps explain the oil return because it affects the cost of holding inventory.

Trading volume is added to account for various unobservable sources of volatility. One unit of volume represents 1,000 executed contracts. Disagreement exists on whether contemporaneous or lagged volume should be used. Foster (1995) concluded that oil volatility and volume are contemporaneously correlated and driven by the same factors, assumed to be information. He showed that lagged volume explains current volatility which means that lagged volume rather than contemporaneous volume should be used as a control variable to avoid endogeneity issues. Kocagil and Shachmurove (1998) corroborated this by providing evidence of two-way Granger causality between oil volatility and volume. Fujihara and Mougoue (1997) argued that volume is a significant explanatory variable for oil volatility even though factors other than volume affect the persistence of volatility. In contrast, Girard, Sinha and Biswas (2008) concluded that volume not only leads oil and gas volatility but is exogenous to it, which implies that it can be used for forecasting volatility and as a proxy for the flow of information, suggesting contemporaneous volume *can* be included in the regressions. For gas, Herbert (1995) concluded that lagged volume influences current price volatility but lagged price volatility has much less of an influence on current volume.

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<sup>30</sup>Alternative specifications are run where the beginning-of-day (end-of-day) dummy took on the value of 1 for the first (last) two and three intervals. The results do not change.

Since the previous papers disagree on whether contemporaneous or lagged volume should be used as a control variable in the volatility regression, both specifications are implemented. The results are very similar. The lagged volume specification is reported in this paper.<sup>31</sup>

Control variables for gasoline inventory, distillate fuel oil (referred to as “distillate”) inventory and refinery utilization are added because these data are included in the Weekly Petroleum Storage Report.<sup>32</sup> Since these data are released at the same time as the oil inventory data, their announcements could possibly skew the results. There are no other weekly announcements made by any U.S. government agency which coincide with the oil and gas inventory announcements.<sup>33</sup>

For the futures *return*, the regression is:

$$R_j = \alpha + \sum_{i=1}^I \beta_i R_{j-i} + \sum_{k=1}^K \sum_{l=0}^L \gamma_{kl} S_{k,j-l} + \sum_{k=1}^K \sum_{l=0}^L \delta_{kl} S_{k,j-l} \times I(S_{k,j-l} > 0) + \sum_{m=1}^M \theta_m \{Z_m\} + \varepsilon_j, \quad (1)$$

where  $\{k\}$  includes oil, gas, gasoline, distillate and refinery utilization,  $i$  and  $l$  stand for lags of returns and surprises, respectively, and  $\{Z_m\}$  includes dummies for the beginning-of-day, end-of-day and the first-trading-day, and controls for trader composition, three-month Treasury bill rate, and lagged volume.

Similarly, for the futures *volatility*, the regression is:

$$|R_j| = \alpha + \sum_{i=1}^I \beta_i |R_{j-i}| + \sum_{k=1}^K \sum_{l=0}^L \gamma_{kl} S_{k,j-l} + \sum_{k=1}^K \sum_{l=0}^L \delta_{kl} S_{k,j-l} \times I(S_{k,j-l} > 0) + \sum_{m=1}^M \theta_m \{Z_m\} + \varepsilon_j. \quad (2)$$

Newey-West standard errors are used to account for heteroskedasticity and autocorrelation in the error term  $\varepsilon_j$ .<sup>34</sup>

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<sup>31</sup>In an alternative method of accounting for various unobservable sources of volatility, the Chicago Board Options Exchange Volatility Index (VIX) is included as a measure of the stock market volatility and investor sentiment in general. The results do not change.

<sup>32</sup>Distillate includes diesel fuels used in on-highway engines, e.g., automobiles and trucks, and off-highway engines, e.g., railroad locomotives and agricultural machinery, as well as fuel oils used for heating and power generation. Refinery utilization is defined as the ratio of gross inputs used in the atmospheric oil distillation units to the operable capacity of the units. For more detail, see Definitions of Petroleum Products and Other Terms on [www.eia.doe.gov](http://www.eia.doe.gov).

<sup>33</sup>The Weekly Petroleum Storage Report includes other data, e.g., propane inventory and jet fuel inventory. However, Bloomberg does not conduct surveys for these commodities. Therefore, they cannot be included in the regression. It is unlikely they would have a major effect on the results of this paper.

<sup>34</sup>Note that the above regressions do not suffer from endogeneity due to a two-way relationship between oil prices and oil inventory because the inventory variable on the right-hand side is not the actual inventory; it is the *unanticipated* component of the inventory changes. As such, it is not a decision variable of the market participants.

Since the oil and gas prices exhibit time-varying volatility depicted in Figures 4 and 5, generalized autoregressive conditional heteroskedasticity (GARCH) models lend themselves as tools for analyzing the data in addition to the OLS. Four specifications are presented. First, the GARCH(1,1) model that includes one ARCH term and one GARCH term with the Gaussian distribution of errors is used as a benchmark:

$$R_j = \alpha + \sum_{i=1}^I \beta_i R_{j-i} + \sum_{k=1}^K \sum_{l=0}^L \gamma_{kl} S_{k,j-l} + \sum_{k=1}^K \sum_{l=0}^L \delta_{kl} S_{k,j-l} \times I(S_{k,j-l} > 0) + \sum_{m=1}^M \theta_m \{Z_m\} + \varepsilon_j, \quad (3)$$

$$h_j^2 = \nu + \phi h_{j-1}^2 + \zeta \varepsilon_{j-1}, \quad (4)$$

where equation (3) is the mean equation, equation (4) is the conditional variance equation, and the distribution of the error conditional on an information set at time  $j$ ,  $\Psi_j$ , is assumed to be  $\varepsilon_j | \Psi_j \sim N[0, h_j^2]$ .

Second, a GARCH(1,1) model with the  $t$  distribution is implemented to account for the distribution's heavy tails. Third, a GARCH-in-mean(1,1) model with the Gaussian distribution that lets the expected value of the return depend on its conditional variance is used. The mean equation then becomes:

$$R_j = \alpha + \sum_{i=1}^I \beta_i R_{j-i} + \sum_{k=1}^K \sum_{l=0}^L \gamma_{kl} S_{k,j-l} + \sum_{k=1}^K \sum_{l=0}^L \delta_{kl} S_{k,j-l} \times I(S_{k,j-l} > 0) + \sum_{m=1}^M \theta_m \{Z_m\} + \psi h_j^2 + \varepsilon_j. \quad (5)$$

Finally, an EGARCH(1,1) model with the Gaussian distribution that allows for an asymmetric reaction to positive and negative innovations is implemented with the conditional variance equation:

$$\log(h_j^2) = \nu + \phi \log(h_{j-1}^2) + \omega \left| \frac{\varepsilon_{j-1}}{\sqrt{h_{j-1}}} \right| + \rho \frac{\varepsilon_{j-1}}{\sqrt{h_{j-1}}}, \quad (6)$$

where the term  $\rho \frac{\varepsilon_{j-1}}{\sqrt{h_{j-1}}}$  captures the asymmetry because positive innovations  $\varepsilon_j > 0$  are allowed to have different effects on the conditional variance than negative innovations  $\varepsilon_j < 0$ .

The above regressions are run for the futures nearby contract as well as the contracts of longer maturities to investigate how current news announcements affect financial instruments at various points in the future.

## 5 Results

### 5.1 Oil Price Volatility

#### 5.1.1 Intraday Pattern Graphs

Figure 6 shows the intraday pattern of oil price volatility.<sup>35</sup> In panel a), absolute returns for each 10-minute interval are averaged across all days in the data sample. In addition to a U-shaped pattern due to the market opening and closing, one feature stands out.<sup>36</sup> The 10:40 a.m. interval shows a spike in volatility. Panels b), c) and d) display the intraday pattern of volatility by day. In panel b), the absolute returns for each interval are averaged only for Mondays. While the U-shaped pattern is still visible, the 10:40 a.m. spike disappears. The graphs for Tuesdays and Fridays, not shown in this paper, look similar. Panel c) shows the intraday volatility pattern for Wednesdays, i.e., the day when the Weekly Petroleum Storage Report is released at 10:30 a.m. As documented by Bjursell, Gentle and Wang (2009), the 10:40 a.m. spike is due to this oil inventory news announcement. However, panel d) for Thursdays shows a similar pattern with a smaller magnitude. This paper hypothesizes that the 10:40 a.m. spike is due to the release of the Weekly Natural Gas Storage Report at 10:30 a.m. This cross-commodity effect, suggesting that the gas market influences the oil market, has not been observed in previous research.<sup>37</sup>

#### 5.1.2 Cross-Commodity Effect

Table 2 shows regression results for the price volatility of the oil nearby futures contract. Specification (1) includes the oil inventory variables as well as control variables that have been used in other papers to explain the oil price volatility, as described in Section 4.<sup>38</sup>

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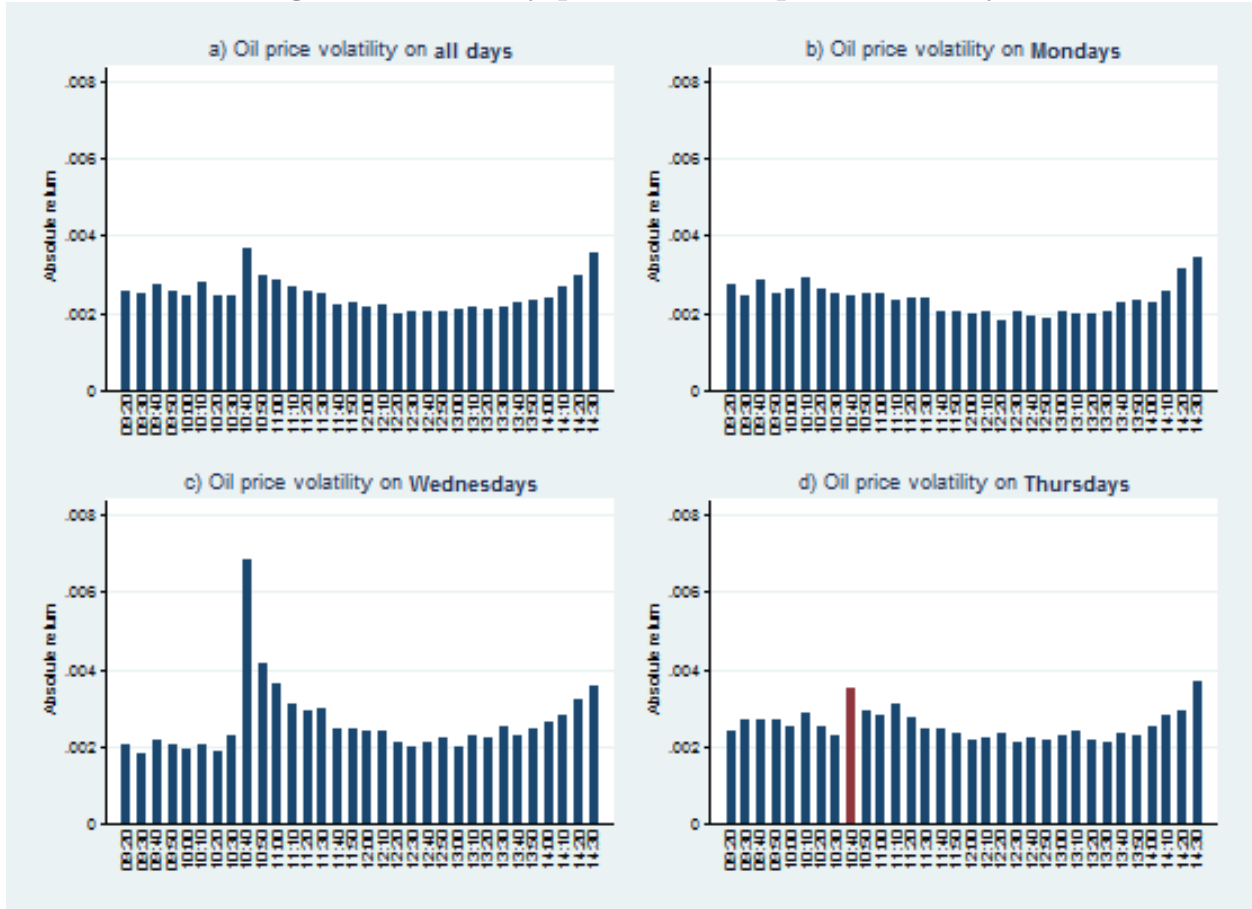
<sup>35</sup>The intraday pattern graphs do not display the first interval to avoid skewing the graphs by the overnight gap as the first interval is affected by not only by the first ten minutes of the trading day but also the period since the market closed on the previous day.

<sup>36</sup>The fact that the data sample includes the period from June 13, 2003 till January 31, 2007 when the market opened at 10 a.m. as well as the period from February 1, 2007 till September 24, 2010 when the market opened at 9 a.m. creates a “double-U” because the volatility is higher after 9 a.m. and after 10 a.m.

<sup>37</sup>The smaller spike on Thursdays in the 11:10 a.m. interval is due to the Weekly Petroleum Storage Report being released on Thursdays at 11:00 a.m. if Monday, Tuesday or Wednesday fall on a holiday, as discussed in Section 3.2.

<sup>38</sup>The first-trading-day dummy, refinery utilization variables, and lags of inventory surprises are not significant, so the specification reported in this paper excludes them.

Figure 6: Intraday pattern of oil price volatility



Notes: This figure shows the intraday pattern of the NYMEX crude oil nearby contract futures price volatility. The volatility is defined as the absolute return. The first interval is not displayed to avoid skewing the graphs by the overnight gap. Source: Tick Data, Inc.

The oil glut variable stands for the situation in which  $S_{kj} > 0$ , i.e.,  $A_{kj} > E_{kj}$ , and the oil shortage variable stands for the situation in which  $S_{kj} < 0$ , i.e.,  $A_{kj} < E_{kj}$ . The coefficient of  $-.00425$  on the oil shortage means that the analysts overforecasting the actual inventory by 1% leads to an  $.00425$  increase in volatility.<sup>39</sup> The coefficient of  $+.00626$  on the oil glut means that the analysts underforecasting the actual inventory by 1% leads to an  $.00626$  increase in volatility. These coefficients are substantial given the intraday absolute returns shown in Figure 6.

Specification (2) adds the gas inventory variables. The oil inventory variables are unaffected which means that the gas inventory variables provide additional explanatory power. The coefficients of  $-.00205$  and  $+.00191$  on the gas shortage and the gas glut are about one-

<sup>39</sup>The change is an increase even though the coefficient has a negative sign because shortage stands for  $S_{kj} < 0$ , so the coefficient is multiplied by a negative number.

half and one-third the size of their oil counterparts, respectively, indicating the gas inventory announcements have a sizeable effect on the oil price volatility. This influence of the gas market on the oil market has not been documented before.

Specification (3) adds control variables for the gasoline and distillate inventory. Even though adding these variables decreases the oil shortage and oil glut coefficients, the gas shortage and gas glut coefficients are unaffected, confirming the cross-commodity effect. In fact, the gas inventory variables become more important relative to the oil inventory variables. The gas shortage coefficient becomes almost as large as the oil shortage coefficient and the gas glut coefficient becomes about half the size of the oil glut coefficient. This cross-commodity effect provides support for the theories on spillovers between the oil and gas markets described in the Introduction.

### 5.1.3 Joint Model of Oil and Gas Price Volatility and the Asymmetry Effect

To put the effect of *gas* inventory announcements on the *oil* price volatility in perspective, the effect of *oil* inventory announcements on the *gas* price volatility is analyzed for comparison. Since errors may be correlated across the oil and gas regressions, a seemingly unrelated regression (SUR) is estimated.<sup>40</sup> Table 3 displays the results for the oil and gas inventory variables. Again, the coefficients are sizeable given the intraday absolute returns shown in Figure 6.

The effect of both *gas gluts and gas shortages* on the *oil* price volatility is more than twice as strong as the effect of *oil gluts and oil shortages* on the *gas* price volatility. This underscores the cross-commodity effect and highlights the importance of the gas market spillovers for the oil market.

In addition to the cross-commodity effect, the joint model results in Table 3 offer an interesting picture of asymmetries. Numerous studies have shown that in stock and bond markets, an unexpected price decrease, i.e., “bad news”, is associated with a higher volatility than an unexpected price increase, i.e., “good news” (e.g., Glosten, Jagannathan and Runkle (1993)). In the oil and gas markets, the evidence is mixed. The finding from the stock and bond markets was corroborated by Susmel and Thompson (1997) using monthly gas data

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<sup>40</sup>The SUR results do not materially differ from running regressions separately for oil and gas.

**Table 2: Price volatility regressions for oil nearby contract**

	(1)	(2)	(3)
Oil shortage $S < 0$	***-.00425 (.00051)	***-.00426 (.00051)	***-.00231 (.00066)
Oil glut $S > 0$	***.00626 (.00074)	***.00627 (.00074)	***.00433 (.00077)
Gas shortage $S < 0$		**-.00205 (.00075)	***-.00209 (.00075)
Gas glut $S > 0$		***.00191 (.00052)	***.00194 (.00053)
Gasoline shortage $S < 0$			**-.00107 (.00048)
Gasoline glut $S > 0$			***.00212 (.00068)
Distillate shortage $S < 0$			**-.00139 (.00062)
Distillate glut $S > 0$			*.00093 (.00051)
Beg-of-day dummy	***.00795 (.00026)	***.00796 (.00026)	***.00797 (.00026)
End-of-day dummy	***.00098 (.00008)	***.00099 (.00008)	***.00100 (.00008)
Trader composition	***-.00010 (.00003)	***-.00010 (.00003)	***-.00010 (.00003)
T-bill rate	***-.00008 (.00001)	***-.00008 (.00001)	***-.00008 (.00001)
Volume 1st lag	***.00006 (.00001)	***.00006 (.00001)	***.00006 .00001
$ R_j $ 1st lag	***.07220 (.01127)	***.07248 (.01129)	***.07239 (.01130)
$R^2$	0.27	0.28	0.28
$RMSE$	0.00318	0.00317	0.00317

*Notes: \*\*\*, \*\* and \* represent 99%, 95% and 90% significance levels, respectively. Standard errors are shown in parenthesis. The number of observations is 54,850 in all specifications. The control variables that are not significant are excluded from the specification reported in this paper. Only the first lags of volume and absolute return are reported to save space.*

from 1975 through 1994 and Wang, Wu and Yang (2008) using intraday gas data from 1995 through 1999. However, Wang, Wu and Yang (2008) did not find any asymmetries in oil. Switzer and El-Khoury (2007) came to the opposite conclusion using daily oil data from 1986 through 2005, showing that positive price shocks lead to higher volatility than negative price shocks. This was also the case in Gregoire and Boucher (2008), who used daily gas data from 2005 through 2007, and Kuper and van Soest (2006), who used monthly oil data from 1970 through 2002.<sup>41</sup>

<sup>41</sup>Note that with the exception of Gregoire and Boucher (2008), these papers on asymmetries did not consider inventories.

**Table 3: SUR model for oil and gas price volatility**

	Oil price volatility	Gas price volatility
Oil shortage $S < 0$	***-.00232 (.00030)	**-.00089 (.00042)
Oil glut $S > 0$	***.00434 (.00030)	** .00089 (.00043)
Gas shortage $S < 0$	***-.00217 (.00061)	***-.02432 (.00087)
Gas glut $S > 0$	***.00200 (.00044)	***.02110 (.00064)

Notes: \*\*\*, \*\* and \* represent 99%, 95% and 90% significance levels, respectively. Standard errors are shown in parenthesis. The number of observations is 54,850. Only the oil and gas inventory variables are reported to save space.

In our findings, price decreases are associated with inventory gluts and price increases are associated with inventory shortages in accordance with laws of demand and supply as shown in Table 6. The relative response of volatility to the price decreases, i.e., inventory gluts, and price increases, i.e., inventory shortages, differs by commodity. A glut has a larger impact than a shortage for the effect of *oil* inventory announcements on *oil* price volatility. In contrast, a glut has a slightly smaller impact than a shortage for the effect of *gas* inventory announcements on *oil* price volatility, which is also the case for the effect of *gas* inventory announcements on *gas* price volatility. Finally, a glut has the same effect as a shortage for the effect of *oil* inventory announcements on *gas* price volatility. This shows the asymmetry depends on the source of the shock and highlights the importance of analyzing the data in detail since general statements may miss the fine differences.

#### 5.1.4 Effect across Futures Contract Maturities

To investigate how current news announcements affect financial instruments at various points in the future, the specification (3) is run for the nearby contract, denoted as Contract 1 and the following seven months' contracts for oil and gas. Since errors may be correlated across the regressions for the different maturities, SUR is applied.<sup>42</sup>

<sup>42</sup>This leads to the slight differences between results for the nearby contract reported in Table 2 that uses OLS and Table 4 that uses SUR. Also, since contracts with longer maturities are traded less frequently, these contracts have more missing observations than the nearby contract. Oil contracts 2 through 8 have 0.42%, 6.79%, 25.69%, 46.43%, 60.76%, 71.30% and 77.54% missing observations, respectively. Gas contracts 2 through 8 have 1.19%, 5.83%, 11.83%, 17.97%, 24.81%, 33.24% and 40.07% missing observations, respectively. As in the nearby contract, the missing observations are set equal to the previous observation. However, since

Table 4 displays the results for the oil and gas inventory variables. See Appendix D for the other regressors. The two-way causality indicated by the cross-commodity effect holds across the maturity structure as the oil and gas inventory variables remain significant for the longer maturities. The asymmetry effect also persists across the maturities. The results described above are, therefore, robust to the maturity structure. In general, the coefficients decrease as the length of the contract increases, supporting the Samuelson (1965) theorem, which states that futures contracts become more volatile as their expiration date approaches.

**Table 4: Price volatility of contracts with longer maturities**

**Panel a): Oil contracts**

	Contract 1	Contract 2	Contract 3	Contract 4	Contract 5	Contract 6	Contract 7	Contract 8
Oil shortage	***-.00223	***-.00197	***-.00185	**-.00067	***-.00124	*-.00057	-.00005	-.00048
$S < 0$	(.00030)	(.00026)	(.00026)	(.00028)	(.00030)	(.00031)	(.00031)	(.00031)
Oil glut	***.00428	***.00352	***.00334	***.00208	***.00224	***.00083	***.00116	-.00043
$S > 0$	(.00031)	(.00027)	(.00027)	(.00029)	(.00031)	(.00031)	(.00032)	(.00032)
Gas shortage	***-.00233	***-.00243	**-.00136	*-.00095	***-.00178	*-.00105	-4.35e-06	-.00021
$S < 0$	(.00062)	(.00054)	(.00054)	(.00058)	(.00063)	(.00063)	(.00065)	(.00064)
Gas glut	***.00241	***.00223	***.00206	***.00135	***.00247	***.00139	***.00167	.00011
$S > 0$	(.00045)	(.00040)	(.00039)	(.00042)	(.00046)	(.00046)	(.00047)	(.00047)

**Panel b): Gas contracts**

	Contract 1	Contract 2	Contract 3	Contract 4	Contract 5	Contract 6	Contract 7	Contract 8
Oil shortage	**-.00096	**-.00080	***-.00116	***-.00105	**-.00070	-.00053	-.00030	-.00001
$S < 0$	(.00043)	(.00041)	(.00038)	(.00035)	(.00035)	(.00033)	(.00034)	(.00032)
Oil glut	**-.00100	.00063	**-.00086	.00035	.00043	*.00061	.00038	***.00104
$S > 0$	(.00044)	(.00041)	(.00038)	(.00036)	(.00036)	(.00034)	(.00035)	(.00033)
Gas shortage	***-.02486	***-.02315	***-.02062	***-.01168	***-.01141	***-.01015	***-.00752	***-.00724
$S < 0$	(.00088)	(.00083)	(.00077)	(.00072)	(.00073)	(.00069)	(.00070)	(.00067)
Gas glut	***.02120	***.02059	***.01782	***.01515	***.01220	***.01194	***.00827	***.00766
$S > 0$	(.00064)	(.00061)	(.00056)	(.00052)	(.00053)	(.00050)	(.00051)	(.00049)

Notes: \*\*\*, \*\* and \* represent 99%, 95% and 90% significance levels, respectively. Standard errors are shown in parenthesis. The number of observations is 54,598. Only the oil and gas inventory variables are reported to save space. See Appendix D for the other regressors.

### 5.1.5 Pre-Announcement and Post-Announcement Effects

The oil and gas inventory announcements affect the oil price volatility even prior to the announcement.<sup>43</sup> The volatility is lower than usual for approximately 70 minutes before the oil announcements and 30 minutes before the gas announcements. After the announcement, the volatility remains higher than usual for approximately 60 minutes following the

the number of missing observations varies across the contracts, an unbalanced SUR is applied as a robustness check. The results do not change. Contracts with maturities longer than eight months do not have significant coefficients on the inventory variables, so they are not reported.

<sup>43</sup>The pre-announcement and post-announcement analysis is performed using dummies for the intervals before and after the announcements.

oil announcements and 20 minutes following the gas announcements. This suggests that the market participants decrease their trading activity while waiting for the inventory report announcements and increase their trading activity once the reports are released.

The oil futures market appears to be approximately as efficient as the gas futures market in absorbing the inventory news announcements since the gas futures volatility remains higher than usual for approximately 40 minutes after the oil announcements and 30 minutes after the gas announcements.

## 5.2 Oil Price Return

This section presents the effect of inventory announcements on the oil futures return. While the effect on the price volatility is significant both statistically and economically, the economic significance of the effect on the oil price return is small as evidenced by the low  $R^2$  in Table 5, although the statistical significance remains.

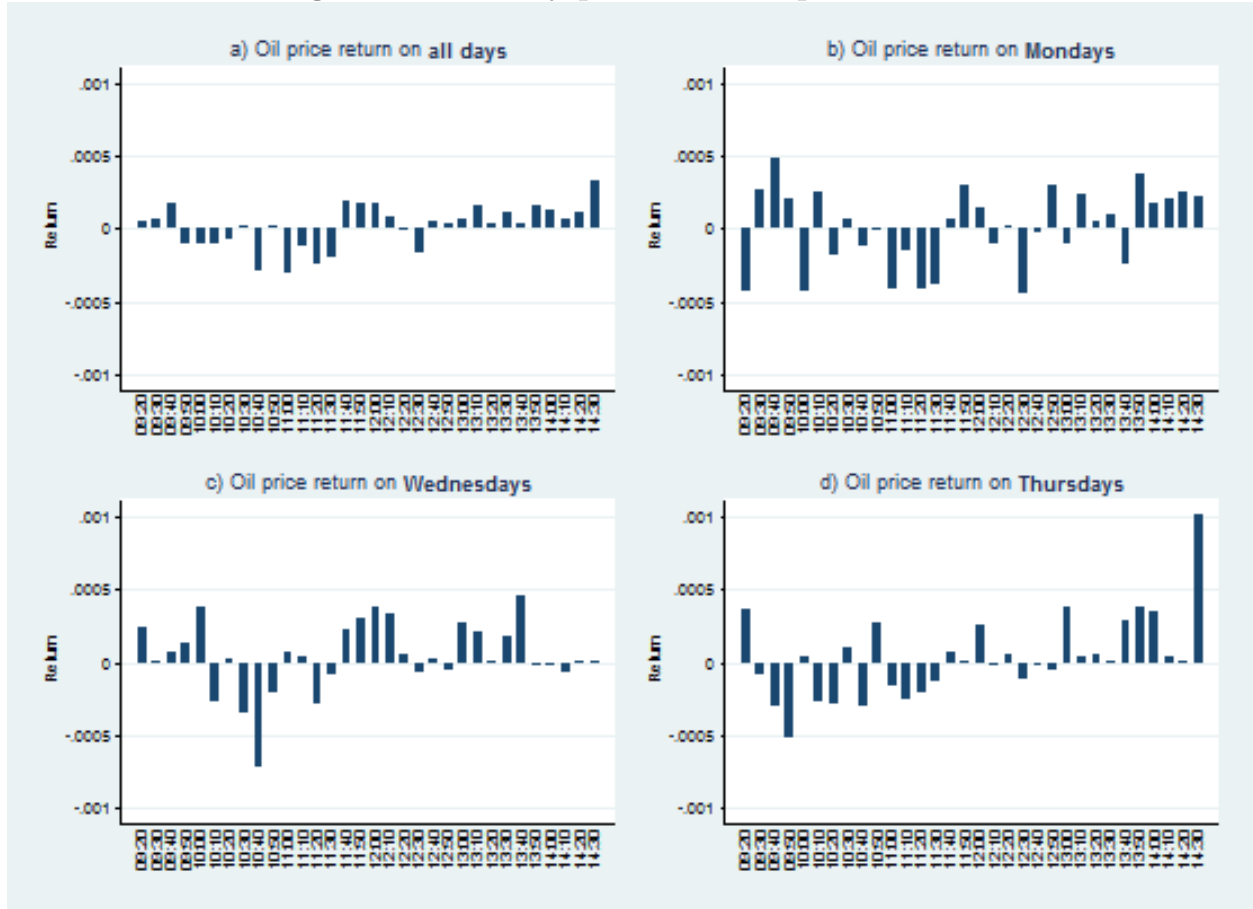
### 5.2.1 Intraday Pattern Graphs

Figure 7 displays the intraday pattern for the oil futures return. Except for a slight drop in the oil price return during the 10:40 a.m. interval on Wednesday, no clear pattern can be discerned around the oil and gas inventory announcement times. In contrast to the oil price volatility that is increased by both shortages and gluts, the oil price return rises as a result of shortages while dropping as a result of gluts. Since the intraday patterns combine both these increases and decreases, no obvious pattern can be seen. The regression results, however, show that both oil and gas inventory announcements do affect the oil futures return.

### 5.2.2 Cross-Commodity Effect

Table 5 shows the same three specifications as Table 2. An oil glut decreases the oil price return while the oil shortage increases it, in accordance with the laws of demand and supply. A gas glut decreases the oil price return, suggesting the two commodities are substitutes. However, a gas shortage has no effect on the oil price return, indicating that the substitutability does not hold for gas shortages.

Figure 7: Intraday pattern of oil price return



Notes: This figure shows the intraday pattern of the NYMEX crude oil nearby contract futures price return. The return is defined as the difference between log prices of two subsequent intervals. The first interval is not displayed to avoid skewing the graphs by the overnight gap. Source: Tick Data, Inc.

### 5.2.3 Joint Model of Oil and Gas Price Return and the Asymmetry Effect

Again, to put the effect of *gas* inventory announcements on the *oil* price return in perspective, the effect of *oil* inventory announcements on the *gas* price return is analyzed, using SUR.

As Table 6 shows, the effect of a *gas* glut on the *oil* price return is as strong as the effect of an *oil* glut on the *gas* price return, highlighting the importance of the gas market for the oil market and providing support for the theories on linkages between the oil and gas markets described in the Introduction. However, while the effect of an oil shortage on the gas price return is significant, the effect of a gas shortage on the oil price return is not, indicating a lack of two-way causality in the gas shortage situations.<sup>44</sup>

<sup>44</sup>When the regression is run without distinguishing between gas gluts and shortages, the gas inventory surprise variable has a significant coefficient of  $-0.00195$ , confounding the asymmetric effect. This shows the importance of distinguishing between the inventory gluts and shortages.

**Table 5: Price return regressions for oil nearby contract**

	(1)	(2)	(3)
Oil shortage $S < 0$	***-.00302 (.00069)	***-.00301 (.00069)	***-.00409 (.00070)
Oil glut $S > 0$	***-.00589 (.00085)	***-.00589 (.00085)	***-.00553 (.00079)
Gas shortage $S < 0$		-.00013 (.00117)	-.00013 (.00117)
Gas glut $S > 0$		***-.00306 (.00074)	***-.00306 .00074
Gasoline shortage $S < 0$			***-.00170 (.00059)
Gasoline glut $S > 0$			***-.00419 (.00075)
Distillate shortage $S < 0$			***-.00351 (.00063)
Distillate glut $S > 0$			***-.00208 (.00060)
Ref util shortage $S < 0$			***.00049 (.00016)
Ref util glut $S > 0$			.00048 (.00050)
End-of-day dummy	** .00031 (.00013)	** .00031 (.00013)	** .00031 (.00013)
$R_j$ 1st lag	*-.01484 (.00846)	*-.01481 (.00846)	*-.01500 (.00846)
$R^2$	0.006	0.007	0.014
$RMSE$	0.00462	0.00462	0.00461

Notes: \*\*\*, \*\* and \* represent 99%, 95% and 90% significance levels, respectively. Standard errors are shown in parenthesis. The number of observations is 54,850 in all specifications. The control variables that are not significant are excluded from the specification reported in this paper. Only the first lag of return is reported to save space.

**Table 6: SUR model for oil and gas price returns**

	Oil price return	Gas price return
Oil shortage $S < 0$	***-.00407 (.00043)	**-.00117 (.00060)
Oil glut $S > 0$	***-.00554 (.00044)	***-.00325 (.00061)
Gas shortage $S < 0$	-.00013 (.00088)	***-.01887 (.00122)
Gas glut $S > 0$	***-.00306 (.00064)	***-.02224 (.00089)

Notes: \*\*\*, \*\* and \* represent 99%, 95% and 90% significance levels, respectively. Standard errors are shown in parenthesis. The number of observations is 54,850. Only the oil and gas inventory variables are reported to save space.

Table 6 also reveals that gluts (i.e., an unexpected excess supply) have a larger impact than shortages (i.e., an unexpected excess demand) on oil and gas price returns.

### 5.2.4 Effect across Futures Contracts Maturities

Table 7 displays specification (3) for the oil and gas nearby contracts as well as the following seven months of contracts. Only the oil and gas inventory variables are reported to save space. See Appendix E for the other regressors.

The cross-commodity effect as well as the asymmetry effect hold across the maturity structure since the oil glut, oil surplus and gas glut variables remain significant for the longer maturities. In general, the coefficients decrease as the length of the contract increases, again providing support for the Samuelson (1965) theorem.

**Table 7: Price return of contracts with longer maturities**

<b>Panel a): Oil contracts</b>								
	Contract 1	Contract 2	Contract 3	Contract 4	Contract 5	Contract 6	Contract 7	Contract 8
Oil shortage $S < 0$	***-.00425 (.00043)	***-.00396 (.00039)	***-.00388 (.00037)	***-.00250 (.00037)	***-.00245 (.00036)	***-.00240 (.00034)	***-.00132 (.00034)	***-.00108 (.00033)
Oil glut $S > 0$	***-.00564 (.00044)	***-.00508 (.00040)	***-.00435 (.00039)	***-.00363 (.00038)	***-.00286 (.00037)	***-.00177 (.00035)	***-.00138 (.00035)	***-.00092 (.00034)
Gas shortage $S < 0$	.00034 (.00088)	.00085 (.00080)	-.00023 (.00077)	.00037 (.00075)	.00108 (.00073)	-.00029 (.00070)	-.00018 (.00069)	.00103 (.00067)
Gas glut $S < 0$	***-.00299 (.00064)	***-.00286 (.00058)	***-.00291 (.00056)	***-.00167 (.00055)	***-.00237 (.00053)	**-.00103 (.00051)	***-.00249 (.00050)	-.00047 (.00049)

<b>Panel b): Gas contracts</b>								
	Contract 1	Contract 2	Contract 3	Contract 4	Contract 5	Contract 6	Contract 7	Contract 8
Oil shortage $S < 0$	**-.00122 (.00060)	***-.00162 (.00056)	***-.00153 (.00051)	***-.00168 (.00047)	***-.00160 (.00045)	***-.00126 (.00041)	-.00063 (.00040)	-.00061 (.00037)
Oil glut $S > 0$	***-.00342 (.00062)	***-.00260 (.00058)	***-.00240 (.00053)	***-.00171 (.00048)	***-.00143 (.00046)	***-.00164 (.00042)	***-.00132 (.00041)	***-.00154 (.00039)
Gas shortage $S < 0$	***-.01853 (.00122)	***-.01702 (.00115)	***-.01637 (.00105)	***-.00977 (.00096)	***-.00899 (.00092)	***-.00997 (.00084)	***-.00732 (.00082)	***-.00718 (.00077)
Gas glut $S < 0$	***-.02269 (.00089)	***-.02210 (.00084)	***-.01878 (.00077)	***-.00159 (.00070)	***-.01290 (.00067)	***-.01322 (.00062)	***-.00930 (.00060)	***-.00819 (.00056)

Notes: \*\*\*, \*\* and \* represent 99%, 95% and 90% significance levels, respectively. Standard errors are shown in parenthesis. The number of observations is 54,682. Only the oil and gas inventory variables are reported to save space. See Appendix E for the other regressors.

### 5.2.5 GARCH Models

In addition to OLS regression, the four GARCH models described in Section 4 are implemented: GARCH(1,1) with a Gaussian distribution of errors, GARCH(1,1) with a  $t$  distribution, GARCH-in-mean(1,1) with a Gaussian distribution and EGARCH(1,1) with a

Gaussian distribution. Conclusions regarding the cross-commodity, asymmetry and maturity structure effects do not change, although some control variables that are not significant in the OLS regression are significant in the GARCH models. See Table 8 for results.

**Table 8: GARCH models**

	(1)OLS	(2)GARCH(1,1)	(3)GARCH(1,1) <i>t</i>	(4)GARCH(1,1)-M	(5)EGARCH
Oil shortage <i>S</i> < 0	***-.00408 (.00070)	***-.00366 (.00020)	***-.00341 (.00024)	***-.00362 (.00020)	***-.00329 (.00020)
Oil glut <i>S</i> > 0	***-.00555 (.00079)	***-.00573 (.00017)	***-.00421 (.00024)	***-.00574 (.00017)	***-.00468 (.00022)
Gas shortage <i>S</i> < 0	-.00015 (.00117)	-.00036 (.00055)	*-.00082 (.00049)	-.00036 (.00055)	.00080 (.00053)
Gas glut <i>S</i> > 0	***-.00307 (.00074)	***-.00213 (.00031)	***-.00207 (.00039)	***-.00213 (.00031)	***-.00234 (.00044)
Gasoline shortage <i>S</i> < 0	***-.00170 (.00059)	***-.00218 (.00016)	***-.00192 (.00023)	***-.00214 (.00016)	***-.00205 (.00021)
Gasoline glut <i>S</i> > 0	***-.00419 (.00075)	***-.00440 (.00017)	***-.00329 (.00025)	***-.00440 (.00017)	***-.00355 (.00023)
Distillate shortage <i>S</i> < 0	***-.00350 (.00063)	***-.00340 (.00013)	***-.00346 (.00022)	***-.00342 (.00014)	***-.00289 (.00018)
Distillate glut <i>S</i> > 0	***-.00208 (.00060)	***-.00167 (.00014)	***-.00214 (.00022)	***-.00167 (.00014)	***-.00160 (.00020)
Ref.utiliz.shortage <i>S</i> < 0	***.00049 (.00016)	***.00038 (.00008)	***.00045 (.00012)	***.00038 (.00009)	***.00027 (.00011)
Ref.utiliz.glut <i>S</i> > 0	.00048 (.00050)	***.00036 (.00011)	*.00033 (.00017)	***.00037 (.00011)	***.00028 (.00013)
Beg-of-day dummy	-.00009 (.00039)	***-.00037 (.00004)	**-.00015 (.00006)	***-.00039 (.00004)	***-.00021 (.00003)
End-of-day dummy	**-.00031 (.00013)	***-.00475 (.00002)	***.00037 (.00006)	***-.00475 (.00002)	***.00052 (.00007)
1st trading day dummy	-.00002 (.00005)	*-.00004 (.00002)	.00003 (.00003)	*-.00004 (.00002)	
Trader composition	-.00001 (.00006)	-.00004 (.00003)	*-.00007 (.00004)	-.00002 (.00003)	
T-bill rate	2.60e-06 (.00001)	***.00002 (-7.06e-06)	**-.00002 (7.57e-06)	***.00002 (7.14e-06)	***-.00004 (2.12e-06)
Volume 1st lag	-4.46e-06 (.00001)	*-5.99e-06 (3.56e-06)	4.29e-07 (4.09e-06)	**-.7.75e-06 (3.58e-06)	
<i>R<sub>j</sub></i> 1st lag	*-.01499 (.00851)	***-.04904 (.00308)	***-.04800 (.00309)	***-.04999 (.00311)	
arch		***.56878 (.00382)	***.00415 (.00026)	***.56878 (.00391)	***-.01060 (.00018)
garch		***.42869 (.00226)	***.99499 (.00030)	***.42822 (.00230)	***.99976 (.00003)
archm $\sigma^2$				***1.37579 (.24542)	
earch-a					***.01807 (.00016)

Notes: \*\*\*, \*\* and \* represent 99%, 95% and 90% significance levels, respectively. Standard errors are shown in parenthesis. Columns 1 through 6 report OLS, GARCH(1,1) with Gaussian distribution of errors, GARCH(1,1) with *t*-distribution, GARCH-in-mean(1,1) with Gaussian distribution and EGARCH(1,1) with Gaussian distribution. Lagged inventory surprise terms are not significant in any specification, so they are not reported. Only the first lags of volume and absolute return are reported to save space. The *t*-distribution shows 3.2 degrees of freedom. Specification (5) is run without the first trading day, trader composition, lagged volume and lagged return to ensure convergence. The OLS results differ slightly from those reported in Table 5 because the specification in Table 10 includes additional control variables to allow comparison to the GARCH models.

## 5.3 Robustness Checks

Robustness checks are performed to ensure that the above results are maintained conditional on the time period, stages of the business cycle, oil and gas price returns, oil and gas price volatility, and oil, gas, gasoline and distillate inventory. Details of these robustness checks are available upon request.

### 5.3.1 Structural Breaks

Since the oil and gas markets were subject to numerous shocks and developments during the sample period, such as the increase in futures trading, the introduction of LNG technology, the development of the shale gas fields, and the explosion of the Deepwater Horizon drilling rig in the Gulf of Mexico followed by a moratorium on U.S. off-shore drilling, the analysis is performed with dummies for individual years to ensure stability across time. The analysis is repeated with dummies for individual months. In addition, a structural break test is performed following Hansen (2001). The results are unaffected, which means that the conclusions of this paper hold despite these considerable shocks and developments in the energy markets.

### 5.3.2 Business Cycle

The sample period includes the most severe recession since the Great Depression. Therefore, the sample is split into booms and recession using the National Bureau of Economic Research dating that identified the recession as beginning in December 2007 and ending in June 2009. The results are unaffected, which means that the results exhibit stability across the business cycle. Since the world economy may be entering a second dip, the sample was split into periods before and after December 2007. Again, the results were unaffected. This stands in contrast to Hess, Huang and Niessen (2008), who found that the effect of macroeconomic news announcements on the commodity index futures was dependent on recessions and booms.

### 5.3.3 Oil and Gas Price Returns

To check that the results are maintained conditional on the oil and gas price returns, dummies taking on the value of 1 for oil and gas prices below their mean and 0 otherwise are created. The oil dummy is significant for the *oil price volatility* with the coefficient of 0.00027 but it does not affect the coefficients on the other variables. The gas dummy is not significant for the *oil price volatility*. Neither dummy is significant for the *oil price return*.

### 5.3.4 Oil and Gas Price Volatility

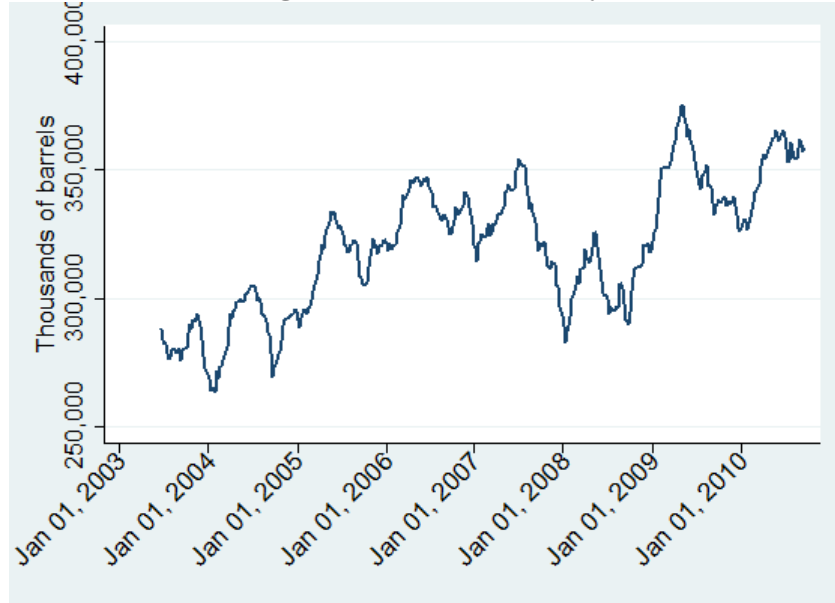
To check that the results are maintained conditional on the oil and gas price volatility graphed in Figures 4 and 5, ratios of the absolute value of the daily return to the absolute value of average daily return for that day of the week are calculated for oil and gas. The oil ratio is significant for the *oil price volatility* with a coefficient of 0.00030 but it does not affect the coefficients on the other variables. The gas ratio is not significant for the *oil price volatility*. The oil ratio is not significant for the *oil price return*. The gas ratio is significant for the *oil price return* with a coefficient of 0.00004 but it does not affect coefficients on the other variables.

### 5.3.5 Oil and Gas Inventory

To check that the results are maintained conditional on the *oil inventory* graphed in Figure 8, a dummy taking on the value of 1 for oil inventory below its mean and 0 otherwise is created. This dummy is significant for the *oil price volatility* with the coefficient of 0.00067. The oil shortage and glut coefficients decrease slightly (by less than 10%) but the gas shortage and glut coefficients are unaffected. The dummy is significant for the *oil price return* with the coefficient of 0.00093 but it does not affect coefficients on the other variables.

To check that the results are maintained conditional on the *gas inventory* graphed in Figure 9, a dummy taking on the value of 1 for gas inventory below its mean and 0 otherwise is created. This dummy is not significant in the *oil price volatility* regression. It is significant with the coefficient of 0.00109 in the *oil price return* regression without affecting the oil shortage, oil glut and gas shortage coefficients. The gas glut coefficient increases by 33%,

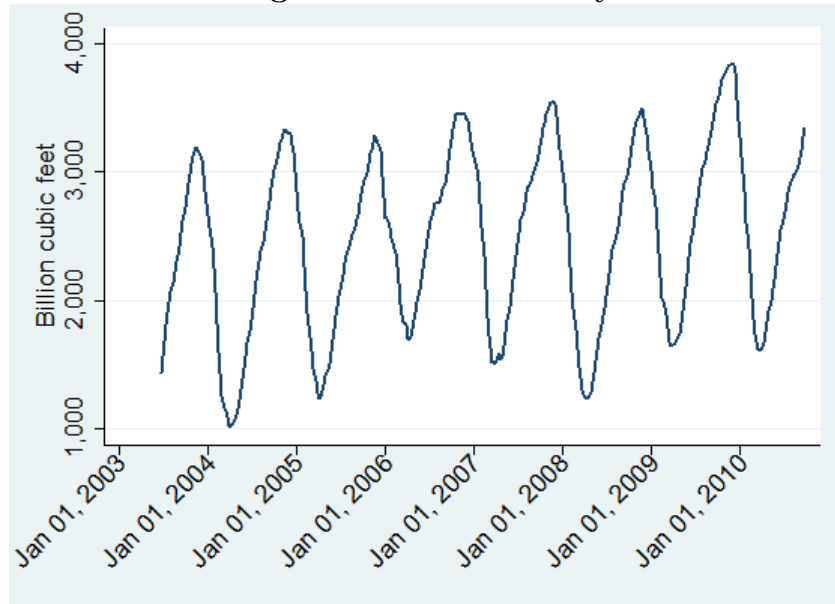
**Figure 8: Oil inventory**



Source: Weekly Petroleum Status Report published by the Energy Information Administration of the U.S. Department of Energy

indicating a higher sensitivity of the oil price return to the gas inventory when the gas inventory is low.

**Figure 9: Gas inventory**



Source: Weekly Natural Gas Storage Report published by the Energy Information Administration of the U.S. Department of Energy

Since the gas inventory is highly seasonal, building up in the summer and drawing down in the winter, a dummy taking on the value of 1 during the build-up periods is created. This

dummy is significant with the coefficient of  $-.00008$  in the *oil price volatility* regression but it does not affect coefficients on the other variables. It is not significant in the *oil price return* regression.

As another check of seasonality, a dummy is added taking on the value of 1 in the winter (defined as the beginning of October until the end of March) and 0 in the summer (defined as the beginning of April until the end of September). This dummy is significant in the *oil price volatility* regression with the coefficient of  $.00003$  but it does not affect the coefficients on the other variables. This dummy is not significant in the *oil price return* regression.

### 5.3.6 Gasoline and Distillate Inventory

To check that the results are maintained conditional on the gasoline inventory, a dummy taking on the value of 1 for the gas inventory below its mean and 0 otherwise is created. The dummy is significant in the *oil price volatility* regression with the coefficient of  $-.00065$  but it does not affect coefficients on the other variables. It is not significant in the *oil price return* regression. Similar results hold for the distillate inventory.

## 6 Conclusions

The previous empirical research on the relationship between crude oil and natural gas markets has concluded the oil market affects the gas market but not vice versa despite economic theory indicating there should be a two-way causality. This paper contributes to solving this puzzle.

There are three main results. First, the bi-directional causality suggested by the theory is confirmed for the first time. These cross-commodity effects turn out to be sizeable. The effect of *gas* inventory announcements on *oil* price volatility is more than twice as strong as the effect of *oil* inventory announcements on *gas* price volatility, highlighting the importance of spillovers from the gas market to the oil market.

Second, the model allows for different reactions of the price volatility and return to inventory gluts and shortages. In contrast to the “good news” vs. “bad news” pattern found in stock and bond markets, the response differs by commodity and type of the shock, which highlights the importance of analyzing the data in detail since general statements may miss

the fine differences.

Third, in contrast to previous studies that analyzed only the nearby futures contract, this paper includes contracts with all maturities to investigate how current news announcements affect financial instruments at various points in the future. The two way-causality as well as the asymmetry effect hold not only for the nearby contract but also for the following seven months' contracts. The results described above are, therefore, robust to the maturity structure. In general, the coefficients decrease as the length of the contract increases, supporting the Samuelson (1965) theorem.

The differences in results between the previous studies and this paper can be attributed to two improvements in analyzing the linkages between the oil and gas markets. First, this study takes advantage of intraday oil and gas prices, i.e., prices at a higher frequency than the daily, weekly or monthly prices used in the previous papers. Second, in contrast to the previous papers that conduct a general analysis of the relationship using, for example, Granger causality tests, this paper analyzes the effect of specific news announcements: the weekly oil and gas inventory reports published by the EIA. While a general analysis using low-frequency data may indicate that the causality runs only from oil to gas, a more careful examination of the high-frequency data focusing on a specific type of a shock, i.e., the inventory news announcements, shows that the causality between the two markets is bi-directional.

Two promising research ideas follow from this paper. First, the asymmetric effects are quite intriguing and call for more research. Second, the pre-announcement and post-announcement effects suggest that market participants decrease their trading activity while waiting for the inventory report announcement and increase their trading activity once the reports are released. This merits a closer look at the relationship between volatility and trading volume. While this relationship in the oil and gas markets has been studied using daily data, an intraday analysis could reveal new facts about how information arrives in the markets. Instead of focusing only on trading during the day, the night trading period could be included to allow for a comparison between these two periods that may differ from the information arrival standpoint. This analysis should again cover futures of all maturities since the different maturities may behave very differently in terms of information arrival.

## Appendix A:

**Table 9: Summary of Papers on *Causality* between Oil and Gas Markets**

Author	Period	Frequency	Futures or Spot Price
Pindyck (2004)	1990-2003	Daily	Futures (NYMEX)
Villar & Joutz (2006)	1989-2005	Daily	Spot (U.S.)
Asche, Osmundsen & Sandsmark (2007)	1995-1998	Monthly	Spot (U.K.)
Brown & Yucel (2007)	1997-2006	Weekly	Spot (U.S.)
Hartley, Medlock & Rosthal (2008)	1990-2006	Monthly	Spot (U.S.)
Onour (2009)	1996-2008	Weekly	Spot (U.S.)

**Table 10: Summary of Papers on *Relationship* between Oil and Gas Markets**

Author	Period	Frequency	Futures or Spot Price
Yucel and Guo (1994)	1947-1974	Annual	Spot (U.S.)
Serletis and Rangel-Ruiz (2004)	1991-2001	Daily	Spot (U.S)
Bachmeier and Griffin(2006)	1990-2004	Daily	Spot (U.S)
Panagiotidis and Rutledge (2007)	1996-2003	Monthly	Spot (U.K.)
Marzo and Zagaglia (2008)	1990-2005	Daily	Futures (NYMEX)
Wang, Wu and Yang (2008)	1995-1999	Intraday	Futures (NYMEX)

## Appendix B: Holidays

The sample period from June 13, 2003 till September 24, 2010 includes 380 weeks. Several scenarios occurred because of holidays:

- **314 weeks:** The oil inventory report was released on Wednesday at 10:30 am and NYMEX was open on Wednesday. The gas inventory report was released on Thursday at 10:30 am and NYMEX was open on Thursday. This is the normal scenario.
- **50 weeks:** The gas inventory report was released on Thursday at 10:30 am and NYMEX was open on Thursday. The oil inventory report was delayed from 10:30 am on Wednesday until 11 am on Thursday because Monday, Tuesday or Wednesday was a public holiday. These Thursdays are: 09/04/03, 10/16/03, 11/13/03, 01/22/04, 02/19/04, 06/03/04, 07/08/04, 09/09/04, 10/14/04, 02/24/05, 06/02/05, 07/07/05, 09/08/05, 10/13/05, 12/29/05, 01/05/06, 01/19/06, 02/23/06, 06/01/06, 07/06/06, 09/07/06, 10/12/06, 12/28/06, 01/04/07, 01/18/07, 02/22/07, 05/31/07, 07/05/07, 09/06/07, 10/11/07, 11/15/07, 12/27/07, 01/03/08, 01/24/08, 02/21/08, 05/29/08, 09/04/08, 10/16/08, 11/13/08, 01/22/09, 02/19/09, 05/28/09, 09/10/09, 10/15/09, 11/12/09, 01/21/10, 02/18/10, 06/03/10, 07/08/10 and 09/09/10. These weeks are not an issue because the data show the oil inventory reports on the day and interval when they were actually released.
- **1 week:** The oil inventory report was delayed until 11 am on Friday because of a snow emergency. The Wednesday affected was 02/10/10. Again, this is not an issue because the data show the oil inventory report on the day and interval when it was released. It is not clear when the gas inventory report was released. This paper assumes it was released on Thursday at 10:30 am. NYMEX was open on all days.
- **3 weeks:** The oil inventory report was released on Wednesday at 10:30 am and NYMEX was open on Wednesday. The gas inventory report was released on Thursdays. However, NYMEX was closed on Thursday. Since NYMEX was also closed on the following Friday, the gas inventory report did not affect the market until Monday.

The Thursdays affected were 07/03/03, 12/23/04 and 12/30/04. The gas inventory data for these three days is eliminated when the intraday file is merged with the gas inventory file because the intraday file does not contain these days. The effect on the market stays in the data because the effect is felt on the following Monday, which is contained in the intraday file. Since this occurs only in three out of 380 weeks, it does not have a material effect on the results.

- **4 weeks:** The oil inventory report was released on Wednesday at 10:30 am and NYMEX was open on Wednesday. The gas inventory report was *not* released on Thursdays because Thursday was a public holiday. It is not clear when the gas inventory report was released, so this paper assumes the release took place at 10:30 am on the following Friday. The Thursdays affected were 11/11/04, 11/23/06, 11/22/07 and 11/27/08. NYMEX was open on all days.
- **5 weeks:** The oil inventory report was released on Wednesday at 10:30 am and NYMEX was open on Wednesday. The gas inventory report was *not* released on Thursdays because Thursday was a public holiday. It is not clear when the gas inventory report was released, so this paper assumes the release took place at 10:30 am on the following Friday. Since NYMEX was closed on both Thursday and Friday, the release probably affected the market on Monday. The gas inventory data for these five days is eliminated when the intraday file is merged with the gas inventory file because the intraday file does not contain these days. The effect on the market stays in the data because the effect is felt on the following Monday, contained in the intraday file. Since this occurs in only five out of 380 weeks, the effect on results is immaterial.
- **3 weeks:** The oil inventory report was released on Wednesday at 10:30 am but NYMEX was closed on Wednesday. The Wednesdays affected are: 12/24/03, 12/31/03 and 11/23/05. The gas inventory report was *not* released on Thursdays because Thursday was a public holiday. It is not clear when the gas inventory report was released, so this paper assumes the release took place at 10:30 am on the following Friday. The Thursdays affected are 12/25/03, 01/01/04 and 11/24/05. NYMEX was closed on Thursday.

# Appendix C: Volatility Signature Plots

Figure 10: Volatility signature plot for oil price

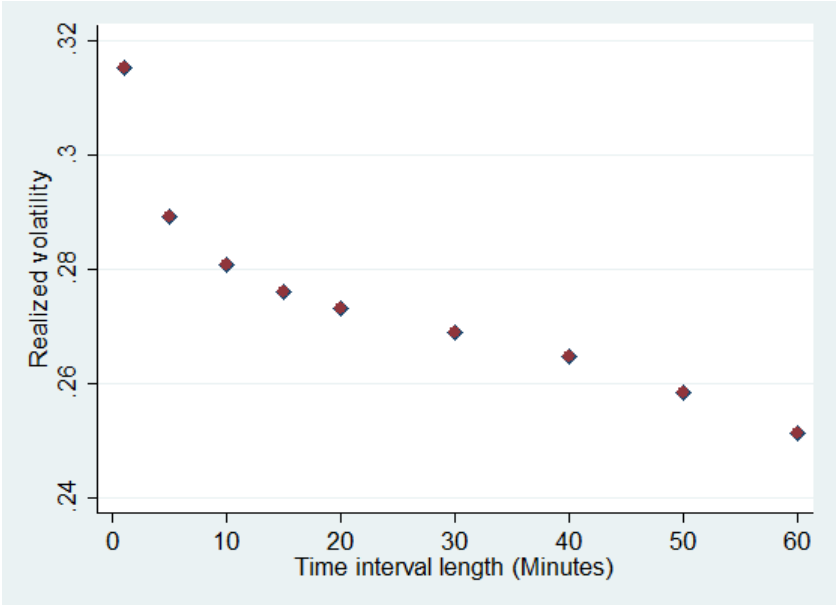
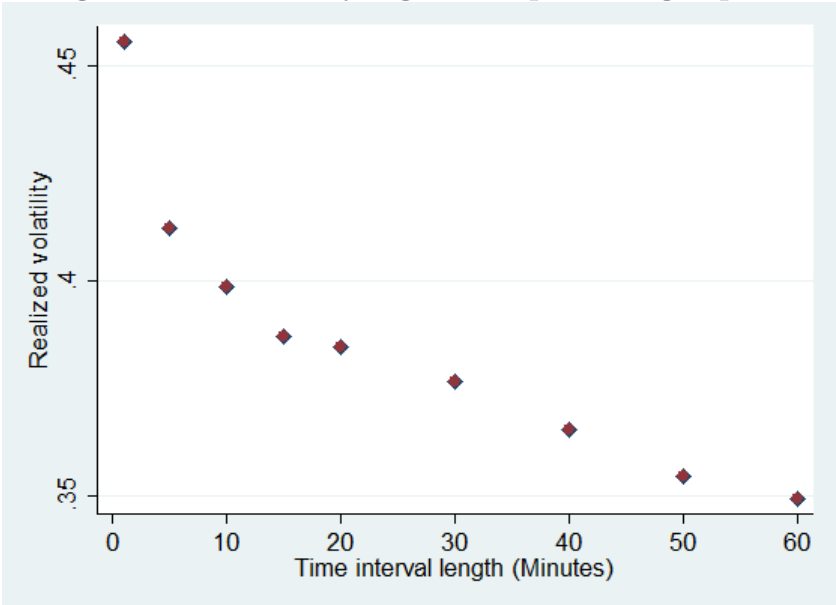


Figure 11: Volatility signature plot for gas price



## Appendix D: Price Volatility of Contracts with Longer Maturities

### Panel a): Oil contracts

	Contract 1	Contract 2	Contract 3	Contract 4	Contract 5	Contract 6	Contract 7	Contract 8
Oil shortage $S < 0$	***-.00223 (.00030)	***-.00197 (.00026)	***-.00185 (.00026)	**-.00067 (.00028)	***-.00124 (.00030)	*-.00057 (.00031)	-.00005 (.00031)	-.00048 (.00031)
Oil glut $S > 0$	***.00428 (.00031)	***.00352 (.00027)	***.00334 (.00027)	***.00208 (.00029)	***.00224 (.00031)	***.00083 (.00031)	***.00116 (.00032)	.00043 (.00032)
Gas shortage $S < 0$	***-.00233 (.00062)	***-.00243 (.00054)	**-.00136 (.00054)	*-.00095 (.00058)	***-.00178 (.00063)	*-.00105 (.00063)	-4.35e-06 (.00065)	-.00021 (.00064)
Gas glut $S > 0$	***.00241 (.00045)	***.00223 (.00040)	***.00206 (.00039)	***.00135 (.00042)	***.00247 (.00046)	***.00139 (.00046)	***.00167 (.00047)	.00011 (.00047)
Gasoline shortage $S < 0$	***-.00099 (.00028)	***-.00104 (.00025)	***-.00070 (.00025)	***-.00148 .00026	***-.00111 (.00029)	***-.00138 (.00030)	-.00016 (.00030)	***-.00129 (.00029)
Gasoline glut $S > 0$	***.00206 (.00030)	***.00205 (.00026)	***.00224 (.00025)	***.00120 (.00027)	***.00120 (.00030)	***.00252 (.00047)	***.00142 (.00031)	***.00124 (.00030)
Distillate shortage $S < 0$	***-.00140 (.00026)	***-.00158 (.00023)	***-.00131 (.00023)	***-.00084 (.00025)	-.00006 (.00027)	.00015 (.00027)	-.00015 (.00028)	.00008 (.00027)
Distillate glut $S > 0$	***.00101 (.00024)	***.00102 (.00021)	***.00056 (.00021)	***.00091 (.00023)	-.00025 (.00024)	*.00045 (.00025)	**-.00054 (.00025)	***-.00068 (.00025)
Beg-of-day dummy	***.00877 (.00008)	***.00811 (.00007)	***.00767 (.00007)	***.00699 (.00007)	***.00475 (.00008)	***.00370 (.00008)	***.00205 (.00008)	***.00151 (.00008)
End-of-day dummy	***.00136 (.00008)	***.00130 (.00007)	***.00155 (.00007)	***.00150 (.00007)	***.00127 (.00008)	***.00100 (.00008)	***.00078 (.00008)	***.00070 (.00008)
Trader composition	***-.00029 (.00002)	***-.00024 (.00002)	***-.00023 (.00002)	.00011 (.00002)	-.00003 (.00002)	-.00002 (.00002)	-.00004 (.00002)	-.00003 (.00002)
T-bill rate	***-0.00024 (9.82e-06)	***-.00023 (8.60e-06)	***-.00021 (8.53e-06)	***-.00019 (9.17e-06)	***-.00017 (9.93e-06)	***-.00015 (9.98e-06)	***-.00013 (.00001)	***-.00010 (9.94e-06)
Volume 1st lag	*6.50e-06 (3.64e-06)	2.15e-06 (6.50e-06)	-.00005 (.00004)	***.00035 (.00011)	***.00048 (.00015)	***.00070 (.00015)	***.00130 (.00023)	***.00124 (.00026)
$ R_j $ 1st lag	***0.01658 (.00270)	***-.01132 (.00243)	***-.01568 (.00268)	***-.01375 (.00323)	***-.01249 (.00379)	.00602 (.00395)	.00127 (.00413)	.00797 (.00420)

Panel b): Gas contracts

	Contract 1	Contract 2	Contract 3	Contract 4	Contract 5	Contract 6	Contract 7	Contract 8
Oil shortage	**-.00096	**-.00080	***-.00116	***-.00105	**-.00070	-.00053	-.00030	-.00001
$S < 0$	(.00043)	(.00041)	(.00038)	(.00035)	(.00035)	(.00033)	(.00034)	(.00032)
Oil glut	**-.00100	.00063	**-.00086	.00035	.00043	*.00061	.00038	***.00104
$S > 0$	(.00044)	(.00041)	(.00038)	(.00036)	(.00036)	(.00034)	(.00035)	(.00033)
Gas shortage	***-.02486	***-.02315	***-.02062	***-.01168	***-.01141	***-.01015	***-.00752	***-.00724
$S < 0$	(.00088)	(.00083)	(.00077)	(.00072)	(.00073)	(.00069)	(.00070)	(.00067)
Gas glut	***.02120	***.02059	***.01782	***.01515	***.01220	***.01194	***.00827	***.00766
$S > 0$	(.00064)	(.00061)	(.00056)	(.00052)	(.00053)	(.00050)	(.00051)	(.00049)
Gasoline shortage	-.00042	-.00049	-4.92e-08	-.00021	-.00039	-.00024	-.00029	.00019
$S < 0$	(.00040)	(.00038)	(1.69e-07)	(.00033)	(.00033)	(.00032)	(.00032)	(.00031)
Gasoline glut	.00044	.00033	.00031	.00015	*.00064	.00031	.00028	**-.00065
$S > 0$	(.00042)	(.00040)	(.00041)	(.00034)	(.00035)	(.00033)	(.00033)	(.00032)
Distillate shortage	***-.00104	-.00099	**-.00065	**-.00069	-.00047	**-.00073	-.00019	-.00040
$S < 0$	(.00038)	(.00036)	(.00033)	(.00031)	(.00031)	(.00029)	(.00030)	(.00028)
Distillate glut	**-.00086	***.00101	**-.00065	**-.00069	*.00050	***.00083	.00002	-.00032
$S > 0$	(.00034)	(.00033)	(.00030)	(.00028)	(.00028)	(.00027)	(.00027)	(.00026)
Beg-of-day dummy	***.01286	***.01218	***.01121	***.01019	***.00868	***.00707	***.00575	***.00469
	(.00011)	(.00010)	(.00010)	(.00009)	(.00009)	(.00009)	(.00009)	(.00008)
End-of-day dummy	***.00102	***.00097	***.00114	***.00099	***.00093	***.00080	***.00082	***.00073
	(.00011)	(.00010)	(.00010)	(.00009)	(.00009)	(.00009)	(.00009)	(.00008)
Trader composition	-.00003	*-.00006	-.00001	.00003	***-.00008	***.00008	***.00010	**-.00006
	(.00003)	(.00003)	(.00003)	(.00003)	(.00003)	(.00003)	(.00003)	(.00003)
T-bill rate	-1.00e-06	-.00001	**-.00002	***-.00003	-.00001	***-.00004	**-.00002	***-.00005
	(.00014)	(.00001)	(.00001)	(.00001)	(.00001)	(.00001)	(.00001)	(.00001)
Volume 1st lag	*5.22e-06	**-.00009	***-.00034	.00016	*.00036	***.00073	**-.00070	***.00256
	(.00001)	(.00003)	(.00012)	(.00017)	(.00021)	(.00028)	(.00031)	(.00044)
$ R_j $ 1st lag	***0.01141	***-.02173	***.02790	***-.03666	***-.04523	***-.03379	***-.03087	***-.01724
	(.00272)	(.00251)	(.00265)	(.00282)	(.00309)	(.00333)	(.00355)	(.00379)

Notes: \*\*\*, \*\* and \* represent 99%, 95% and 90% significance levels, respectively. Standard errors are shown in parenthesis. The number of observations is 54,598. Only the first lags of volume and absolute return are reported to save space.

## Appendix E: Price Return of Contracts with Longer Maturities

### Panel a): Oil contracts

	Contract 1	Contract 2	Contract 3	Contract 4	Contract 5	Contract 6	Contract 7	Contract 8
Oil shortage $S < 0$	***-.00425 (.00043)	***-.00396 (.00039)	***-.00388 (.00037)	***-.00250 (.00037)	***-.00245 (.00036)	***-.00240 (.00034)	***-.00132 (.00034)	***-.00108 (.00033)
Oil glut $S > 0$	***-.00564 (.00044)	***-.00508 (.00040)	***-.00435 (.00039)	***-.00363 (.00038)	***-.00286 (.00037)	***-.00177 (.00035)	***-.00138 (.00035)	***-.00092 (.00034)
Gas shortage $S < 0$	.00034 (.00088)	.00085 (.00080)	-.00023 (.00077)	.00037 (.00075)	.00108 (.00073)	-.00029 (.00070)	-.00018 (.00069)	.00103 (.00067)
Gas glut $S < 0$	***-.00299 (.00064)	***-.00286 (.00058)	***-.00291 (.00056)	***-.00167 (.00055)	***-.00237 (.00053)	**-.00103 (.00051)	***-.00249 (.00050)	-.00047 (.00049)
Gasoline shortage $S < 0$	***-.00177 (.00041)	***-.00185 (.00037)	***-.00146 (.00036)	***-.00120 (.00035)	***-.00121 (.00034)	***-.00127 (.00033)	**-.00067 (.00032)	***-.00107 (.00031)
Gasoline glut $S > 0$	***-.00420 (.00043)	***-.00399 (.00039)	***-.00401 (.00037)	***-.00242 (.00036)	***-.00304 (.00030)	***-.00173 (.00034)	***-.00179 (.00033)	***.00060 (.00028)
Distillate shortage $S < 0$	***-.00333 (.00040)	***-.00318 (.00036)	***-.00249 (.00035)	***-.00238 (.00034)	***-.00212 (.00033)	***-.00081 (.00032)	*-.00059 (.00031)	***-.00106 (.00030)
Distillate glut $S < 0$	***-.00222 (.00037)	***-.00208 (.00033)	***-.00173 (.00032)	***-.00135 (.00031)	-.00038 .00030	**-.00070 (.00029)	***-.00091 (.00029)	**-.00060 (.00028)
Ref util shortage $S < 0$	***-.00045 (.00015)	**-.00035 (.00014)	*.00024 (.00013)	*-.00022 (.00013)	**-.00029 (.00013)	.00019 (.00012)	*-.00023 (.00012)	***.00033 (.00012)
Ref util glut $S < 0$	.00047 (.00030)	.00041 (.00027)	.00026 (.00026)	-.00026 (.00025)	-.00013 (.00025)	-.00012 (.00024)	***.00025 (.00023)	-.00033 (.00022)
End-of-day dummy	**-.00034 (.00011)	***.00043 (.00010)	***.00050 (.00010)	***.00046 (.00010)	***.00045 (.00009)	***.00037 (.00009)	.00009 (.00009)	***.00033 (.00008)
$R_j$ 1st lag	***-.25723 (.00251)	***-.28124 (.00229)	***-.26616 (.00248)	***-.19238 (.00301)	***-.11405 (.00358)	***-.06849 (.00380)	***-.04759 (.00404)	***-.03016 (.00412)

Panel b): Gas contracts

	Contract 1	Contract 2	Contract 3	Contract 4	Contract 5	Contract 6	Contract 7	Contract 8
Oil shortage	**-.00122	***-.00162	***-.00153	***-.00168	***-.00160	***-.00126	-.00063	-.00061
$S < 0$	(.00060)	(.00056)	(.00051)	(.00047)	(.00045)	(.00041)	(.00040)	(.00037)
Oil glut	***-.00342	***-.00260	***-.00240	***-.00171	***-.00143	***-.00164	***-.00132	***-.00154
$S > 0$	(.00062)	(.00058)	(.00053)	(.00048)	(.00046)	(.00042)	(.00041)	(.00039)
Gas shortage	***-.01853	***-.01702	***-.01637	***-.00977	***-.00899	***-.00997	***-.00732	***-.00718
$S < 0$	(.00122)	(.00115)	(.00105)	(.00096)	(.00092)	(.00084)	(.00082)	(.00077)
Gas glut	***-.02269	***-.02210	***-.01878	***-.00159	***-.01290	***-.01322	***-.00930	***-.00819
$S < 0$	(.00089)	(.00084)	(.00077)	(.00070)	(.00067)	(.00062)	(.00060)	(.00056)
Gasoline shortage	***-.00187	***-.00150	***-.00139	***-.00130	**-.00100	***-.00121	*-.00066	*-.00059
$S < 0$	(.00057)	(.00054)	(.00049)	(.00045)	(.00043)	(.00040)	(.00038)	(.00036)
Gasoline glut	***-.00161	***-.00162	***-.00138	***-.00154	***-.00165	***-.00134	**-.00093	**-.00083
$S > 0$	(.00059)	(.00055)	(.00051)	(.00046)	(.00044)	(.00041)	(.00040)	(.00037)
Distillate shortage	***-.00201	***-.00182	***-.00139	***-.00112	***-.00144	***-.00109	***-.00120	-.00036
$S < 0$	(.00055)	(.00052)	(.00047)	(.00043)	(.00040)	(.00038)	(.00037)	(.00035)
Distillate glut	***-.00207	***-.00193	***-.00170	***-.00144	***-.00164	***-.00137	-.00051	**-.00066
$S < 0$	(.00051)	(.00048)	(.00043)	(.00040)	(.00038)	(.00035)	(.00034)	(.00032)
Ref util shortage	-.00029	-.00016	.00006	.00004	-3.83e-06	.00009	*-.00025	.00007
$S < 0$	(.00021)	(.00020)	(.00018)	(.00017)	(.00016)	(.00015)	(.00014)	(.00013)
Ref util glut	**-.00081	**-.00086	**-.00084	*-.00057	***.00081	*.00050	.00028	***.00087
$S < 0$	(.00041)	(.00039)	(.00035)	(.00032)	(.00024)	(.00029)	(.00028)	(.00026)
End-of-day dummy	*.00025	***.00037	***.00045	**-.00027	***.00028	**-.00024	*.00019	.00014
	(.00015)	(.00014)	(.00013)	(.00012)	(.00011)	(.00011)	(.00010)	(.00010)
$R_j$ 1st lag	***-.23732	***-.24094	***-.24090	***-.23095	***-.21414	***-.17926	***-.14071	***-.10568
	(.00257)	(.00241)	(.00251)	(.00268)	(.00290)	(.00312)	(.00343)	(.00362)

Notes: \*\*\*, \*\* and \* represent 99%, 95% and 90% significance levels, respectively. Standard errors are shown in parenthesis. The number of observations is 54,598. Only the first lag of return is reported to save space.

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