HIGH PRICE VOLATILITY AND SPILLOVER EFFECTS IN ENERGY MARKETS

Aaron Singh
Graduate Student
Department of Agricultural and Applied Economics
The University of Georgia
Athens, GA 30602-7509
Email: singhaa@uga.edu

Berna Karali
Assistant Professor
Department of Agricultural and Applied Economics
The University of Georgia
Athens, GA 30602-7509
Telephone: (706) 542-0750
Fax: (706) 542-0739
Email: bkarali@uga.edu

Octavio A. Ramirez
Professor
Department of Agricultural and Applied Economics
The University of Georgia
Athens, GA 30602-7509
Telephone: (706) 542-2481
Fax: (706) 542-0739
Email: oramirez@uga.edu

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Abstract

We analyze the time-varying volatility in crude oil, heating oil, and natural gas futures markets by incorporating changes in important macroeconomic variables and major political and weather-related events into the conditional variance equations. We allow asymmetric responses to random disturbances in each market as well as to good and bad economic news in the overall economy. We also investigate whether there are spillover effects among these energy markets. A bi-directional volatility spillover effect is found between heating oil and natural gas markets. Among the macro variables considered the spread between the 10-year and 2-year Treasury constant maturity rate is found to have a positive relationship between the volatilities of all commodities. The events that had a major impact on the volatilities of energy commodities include the September 11th terrorist attacks, hurricane Katrina, and the 2008 U.S. financial crisis. The theory of storage is not supported in any of the three commodities. Seasonality and day-of-the week effects are found for all three commodities.

Key words: Asymmetric shocks, energy markets, GARCH, oil, spillover effects, volatility

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Introduction

Since the summer of 2008, energy futures prices have experienced high volatility including a dramatic drop in oil prices from a record high level to less than half the value in just a few months. In conjunction, investors have been faced with high levels of uncertainty about equity markets and the direction of economic policy, resulting in higher volatility in commodity prices. As a result of this volatility, the Chicago Mercantile Exchange Group introduced new crude oil volatility index futures and options contracts based on volatility indexes calculated by the Chicago Board of Options Exchange to help producers and traders to track and trade on the volatility in crude oil. The index calculations use prices from the exchange's active and liquid options on futures markets to create new and effective measures of expected volatility. This introduction of new contracts presents a number of new opportunities for hedging/managing/speculating price risk, but also presents new challenges because of the difficulty of measuring expected volatility.

To measure expected volatility, it is very important to understand the relationship between different energy products, their price determinants, and the underlying factors behind their price fluctuations. Crude oil is a large component of production costs for heating oil and gasoline, and therefore fluctuations in the price of crude oil should result in corresponding fluctuations in heating oil and gasoline prices. In fact, volatilities of crude oil, heating oil, and gasoline are found to be highly correlated (Pindyck, 2001). On the other hand, crude oil is a close substitute for natural gas as an energy source, and thus crude oil price fluctuations should also affect natural gas prices (Mu, 2007). Further, volatility transmission between oil and natural gas markets has been found (Ewing et al., 2002). Consequently, it is important to analyze all these markets simultaneously to determine the factors behind their price volatility.

Price determinants include demand and supply factors. Weather plays an important role in the demand side of energy markets. Colder than normal temperatures in winter and hotter than normal temperatures in summer can increase natural gas demand and push up prices. Demand for crude oil and heating oil peaks in winter as well. Economic growth results in increased demand for goods and services from the commercial and industrial sectors, and therefore generates an increase in demand for both crude oil and natural gas. On the supply side, OPEC decisions about production and prices, political events, storage levels, and natural events are among the determinants of energy prices. Macroeconomic factors affecting energy prices have been also studied in the literature. Some of the variables found to affect energy prices include bilateral exchange rates, price indices, monetary aggregates (Zagaglia, 2010); convenience yield (Lin and Duan, 2007); Treasury bill yields, equity dividend yields, and junk bond premiums (Bessembinder and Chan, 1992).

The goal of this study is to simultaneously estimate the price volatility in energy markets while accounting for spillover effects across different commodities. Daily settlement prices of the nearby crude oil, heating oil, and natural gas futures contracts are included in the empirical analysis. Further, macroeconomic indicators, including percentage changes in consumer price index, industrial production index, and inventory levels as well as the spread between the ten- and two-year constant maturity Treasury bonds are used to test whether these variables affect energy price volatility. These macroeconomic factors help to examine volatility trends during different periods of the business cycle. For instance, volatility in oil futures recently fell slightly as industrial production rose more than expected in December 2010. Thus, our results can assist market participants in better understanding which direction volatility in energy markets go when the levels of these macroeconomic factors change.

We also analyze the impact of major political events, such as changes in OPEC policies, on energy price volatility. This is important because OPEC recently released a statement in late winter of 2010 saying that maintaining current oil prices in a range of $80-$100 would be ideal. In April 2011, the ICE Brent Crude oil surpassed this level by far, closing at around $125 for a few consecutive days. Major natural events like hurricane Katrina is used to account for supply shocks. To capture the impact of weather monthly dummy variables are used.

We use a multivariate GARCH model to simultaneously estimate, the spillover effects across energy markets as well. Our study answers the following research questions: Does volatility in crude oil prices have a spillover effect on the volatilities of natural gas and heating oil? Which economic and natural factors most explain volatility in energy markets? Is the theory of storage supported in energy futures markets? Are there leverage effects, i.e. asymmetric response to positive and negative shocks?

Literature Review

Over the last few decades, the United States has seen substantial increases in energy use and dependence on other countries, causing energy prices to rise. Crude oil and gasoline prices are particularly of great concern. Oil has become the most traded commodity worldwide as both developed and developing economies have seen growth and increased demand for energy. Crude oil has an effect on households as its price would affect gasoline and fuel prices and thus would alter consumers' decisions on travel and purchases of related items, such as automobiles. For example, Kilian (2008) showed that an unanticipated energy price increase of about one percent caused a decrease of almost the same magnitude in the purchases of motor vehicles and parts. Furthermore, the real consumption of domestic automobiles has decreased compared to foreign automobiles. This was because the U.S. consumers typically perceive domestic automobiles[1] as less fuel-efficient.

Energy price shocks affect not only consumer side, but also non-residential investment or business consumption. Oil can be seen as an intermediate good that is used in the production of final goods. Thus, if oil prices are high then firms will lower their production and this will, in turn, cause a contraction in the economy. Both crude oil and natural gas prices have been more volatile than almost all producer products from 1945 to 2005 (Regnier, 2007). Oil price uncertainty has been found to have negative and significant effect on the average growth rate of real economic activity (Rahman and Serletis, 2010) and hence should be addressed carefully by policy makers. The effect of oil price uncertainty on non-residential investments has been documented by Elder and Serletis (2010). Domestic mining expenditures were found to decrease substantially when there was a decrease in oil prices. However, mining expenditures were found to increase very little when there was an increase in oil prices. One thing to note is that in this study,

[1] The U.S. Bureau of Economic Analysis defines domestic cars as cars assembled in the U.S., Canada, and Mexico.

oil price uncertainty was very low during the period of 2002-2008 even though oil prices were on a continual rise during that time. This can help to explain why there weren't more recessionary times even though the continuous rise in oil price would suggest that economic downturns would be more prevalent. In earlier studies, however, Hamilton (1983, 2004) showed that all post-war U.S. recessions were preceded by increases in oil prices. Additionally, in his 1983 paper, he found that recessions typically lag large increases in crude oil prices by three to four months. The only exception was the recession of 1960-1961.

The United States officially entered into a recession in December 2007 and exited in June 2009. Since then, the U.S. economy has been experiencing what some economists term as sluggish growth and this rate has been revised to 1.9 percent in the first quarter of 2011. During this time period crude oil prices hit a little over $140 per barrel, which was the all time high. Since then, crude oil price has substantially dropped to less than half of its all time high, and as of early July 2011 trades around $96 per barrel for the August contract. In the summer of 2008 there was a substantial upsurge in commodity prices, which emerged after the Federal Reserve started being open about additional expansionary monetary policy (Lanman and Miller, 2008). Such a price increase is important to note, since the U.S. was in the midst of an economic downturn and intuitively one would expect much lower oil and energy prices due to decreased demand. One example would be the Asian financial crisis in 1997, which started by the devaluation of the Baht and spread through other Asian countries. This caused a major slowdown in energy demand by developing countries and as a result oil price dropped to

$8 per barrel by the end of 1998. Olowe (2010) showed that the Asian financial crisis did have an impact on crude oil price returns whereas the global crisis of 2008 did not.

Structural changes, such as OPEC's pricing change in April 1999, have been shown to have an effect on oil price volatility (Lee and Zyren, 2007). OPEC reduced quotas to boost oil prices after their low levels seen in 1997. As recent as January 2011, OPEC has come under scrutiny as many questioned if they would alter their production in the wake of oil prices reaching the upper bound of the $80-$100 price range that OPEC deemed "satisfactory."

Crude oil and natural gas are substitutes as inputs in production, or as sources of energy. This relationship is key to both consumers and producers of energy products as the price dynamics of both would dictate whether to increase or decrease inventories, or even alter the rates of substitution between the two. As such, there have been studies that analyzed cointegration of both natural gas and crude oil prices, and natural gas and heating oil prices. Serletis and Herbert (1999), for instance, studied daily Henry Hub and Transco Zone 6 natural gas prices, fuel oil, and power prices. They found that these three fuel prices (except for power price) were all cointegrated. Serletis and Rangel-Ruiz (2004) found a decoupling in daily natural gas and crude oil prices from January 1991 to April 2001. This meant that there were no common or codependent cycles between the prices of natural gas and crude oil. In a later study, using an error-correction model Brown and Yucel (2008) found natural gas and crude oil prices to be cointegrated in the long run. However, they also found that in the short-run, natural gas prices could deviate from crude oil prices because of factors such as inventory levels and weather. Building on the literature on the relationship between natural gas and crude oil, Hartley et al.

(2008) found that crude oil and natural gas have an indirect relationship via heating oil. Additionally, in agreement with Brown and Yucel (2008) they found that factors such as weather, hurricanes, and inventory levels all had significant effects on the short run relationship between natural gas and crude oil prices. This is especially important for commercial users of both commodities, as they may want to change their inventories accordingly.

Commodity markets exhibit seasonality as shown by Suenaga et al. (2008). Volatility of natural gas was found to be greater in winter than it is in summer. Intuitively, one would expect higher volatility of natural gas prices during winter as businesses and households increase their demand for heating and energy use. Weather and storage of natural gas also ties into seasonality, as there are different weather patterns during different seasons and it is necessary to store a commodity when there is scarcity. Natural gas and crude oil spot prices have been shown to have a negative correlation with inventories (Geman and Ohana, 2009). This correlation increases substantially during winter months. This evidence is vital to businesses that experience increases in heat and other energy demand in winter.

Volatility spillovers and asymmetries are important to investors in order to build an optimal portfolio. Spillover effects are indirect externalities that arise from and are caused by some other phenomenon i.e., a change or shock in one sector that has an effect that carries over to another sector. Chang et al. (2010) found spillover effects from Brent crude futures returns to Brent crude spot and forward returns. Additionally, there were spillover effects from WTI futures returns to Brent spot returns and from Brent spot to WTI spot returns. These were all in one direction as stated and there were not many spillover effects that moved in both directions. Furthermore, spillover effects were found in crude oil, gasoline, and heating oil markets (Hammoudeh et al., 2003) particularly in nearby futures contracts and spot prices. Volatility transmission was found in spot, one-month, and three-month prices for WTI crude oil and was more prevalent than mean returns transmission. Both gasoline and heating oil had volatility transmission from the spot prices to the one- and three-month prices as well, where they were each different for mean returns transmission. Ewing et al. (2002) documented volatility transmission between crude oil and natural gas markets, showing that oil volatility depended on past volatility of natural gas, whereas natural gas volatility depended on unexpected events.

Our study builds on this extensive literature and focuses on the economic determinants of volatility in crude oil, heating oil, and natural gas futures markets as well as on the spillover effects across these markets.

Model

The autoregressive conditional heteroskedasticity (ARCH) model was first introduced by Engle (1982) and has been widely used to measure volatility in financial markets. In this model the variance of the current error term is a function of the squared past error terms. This model was later generalized by Bollerslev (1986) to include lagged values of the variance as well and called the generalized autoregressive conditional heteroskedasticity (GARCH) model. GARCH models are found to be useful in explaining stock price distributions (Bollerslev, 1987; Bollerslev et al. 1988; French et al., 1987; Balliie and DeGennaro, 1990). It has been shown that commodity futures prices also exhibit time-varying volatility and can be effectively studied using GARCH models (Baillie and

Myers, 1991; Myers, 1991; Myers and Hanson, 1993; Yang and Brorsen, 1993; Goodwin and Schnepf, 2000).

We adopt the multivariate GARCH-BEKK model developed by Engle and Kroner (1995) in our study and modify it to include exogenous variables that might have an impact on the conditional volatility. We measure the daily return from holding a futures contract on day *t* as

$$r_t = 100 \times \left(\ln F_t - \ln F_{t-1}\right), \tag{1}$$

where F_t is daily settlement price of the futures contract on day *t*. The mean equation of daily returns is then defined as a function of its past values and a random disturbance term. Denoting the vector of mean returns by R_t, the multivariate GARCH in matrix form is given by:

$$R_t = \mu + \sum_{i=1}^{p} R_{t-i} + u_t, \qquad u_t \sim MVN(0, H_t), \tag{2}$$

where R_t is a 3x1 vector consisting of r_t's of each commodity, *p* is the order of autoregressive process, and u_t is the disturbance vector. The conditional covariance matrix of the disturbance term is then given by:

$$H_t = C'C + A'u_{t-1}u'_{t-1}A + B'H_{t-1}B + D'v_{t-1}v'_{t-1}D + G'GX_t, \tag{3}$$

where $v_{t-1} = u_{t-1} \mathrm{I}_{u<0}$, which replicates the vector u_{t-1} with positive elements zeroed out. H_t is a 3x3 symmetric matrix with variances on the diagonal and covariances off the diagonal. *C* is a 3x3 lower triangular matrix of constants, *A* is a 3x3 matrix of ARCH parameters, *B* is a 3x3 matrix of GARCH parameters, *D* is a 3x3 matrix that measures asymmetric ARCH effects and G is 3x3 lower triangular coefficient matrix on the exogenous variables X_t. The matrices are as follows:

$$H_t = \begin{bmatrix} h_{11,t} & h_{12,t} & h_{13,t} \\ h_{12,t} & h_{22,t} & h_{23,t} \\ h_{13,t} & h_{23,t} & h_{33,t} \end{bmatrix}, \quad C = \begin{bmatrix} c_{11} & 0 & 0 \\ c_{21} & c_{22} & 0 \\ c_{31} & c_{32} & c_{33} \end{bmatrix}, \quad A = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix},$$

$$B = \begin{bmatrix} b_{11} & b_{12} & b_{13} \\ b_{21} & b_{22} & b_{23} \\ b_{31} & b_{32} & b_{33} \end{bmatrix}, \quad D = \begin{bmatrix} d_{11} & d_{12} & d_{13} \\ d_{21} & d_{22} & d_{23} \\ d_{31} & d_{32} & d_{33} \end{bmatrix}, \quad G = \begin{bmatrix} g_{11} & 0 & 0 \\ g_{21} & g_{22} & 0 \\ g_{31} & g_{32} & g_{33} \end{bmatrix},$$

where the subscripts 1, 2, and 3 represent, respectively, crude oil, heating oil, and natural gas. Matrix manipulation yields the conditional variance equations shown as:

$$h_{11,t} =$$

$$c_{11}^2 + c_{21}^2 + c_{31}^2 + a_{11}^2 u_{1,t-1}^2 + a_{21}^2 u_{2,t-1}^2 + a_{31}^2 u_{3,t-1}^2 + 2a_{11}a_{21}u_{1,t-1}u_{2,t-1} + 2a_{11}a_{31}u_{1,t-1}u_{3,t-1} + 2a_{21}a_{31}u_{2,t-1}u_{3,t-1} +$$
$$b_{11}^2 h_{11,t-1} + b_{21}^2 h_{22,t-1} + b_{31}^2 h_{33,t-1} + 2b_{11}b_{21}h_{12,t-1} + 2b_{11}b_{31}h_{13,t-1} + 2b_{21}b_{31}h_{23,t-1} + d_{11}^2 v_{1,t-1}^2 + d_{21}^2 v_{2,t-1}^2 + d_{31}^2 v_{3,t-1}^2 +$$
$$2d_{11}d_{21}v_{1,t-1}v_{2,t-1} + 2d_{11}d_{31}v_{1,t-1}v_{3,t-1} + 2d_{21}d_{31}v_{2,t-1}v_{3,t-1} + (g_{11}^2 + g_{21}^2 + g_{31}^2)X_t \tag{4}$$

$$h_{22,t} =$$

$$c_{22}^2 + c_{32}^2 + a_{12}^2 u_{1,t-1}^2 + a_{22}^2 u_{2,t-1}^2 + a_{32}^2 u_{3,t-1}^2 + 2a_{12}a_{22}u_{1,t-1}u_{2,t-1} + 2a_{12}a_{32}u_{1,t-1}u_{3,t-1} + 2a_{22}a_{32}u_{2,t-1}u_{3,t-1} +$$
$$b_{12}^2 h_{11,t-1} + b_{22}^2 h_{22,t-1} + b_{32}^2 h_{33,t-1} + 2b_{12}b_{22}h_{12,t-1} + 2b_{12}b_{32}h_{13,t-1} + 2b_{22}b_{32}h_{23,t-1} + d_{12}^2 v_{1,t-1}^2 + d_{22}^2 v_{2,t-1}^2 + d_{32}^2 v_{3,t-1}^2$$
$$+ 2d_{12}d_{22}v_{1,t-1}v_{2,t-1} + 2d_{12}d_{32}v_{1,t-1}v_{3,t-1} + 2d_{22}d_{32}v_{2,t-1}v_{3,t-1} + g_{22}^2 + g_{32}^2 X_t \tag{5}$$

$$h_{33,t} =$$

$$c_{33}^2 + a_{13}^2 u_{1,t-1}^2 + a_{23}^2 u_{2,t-1}^2 + a_{33}^2 u_{3,t-1}^2 + 2a_{13}a_{23}u_{1,t-1}u_{2,t-1} + 2a_{13}a_{33}u_{1,t-1}u_{3,t-1} + 2a_{23}a_{33}u_{2,t-1}u_{3,t-1} +$$
$$b_{13}^2 h_{11,t-1} + b_{23}^2 h_{22,t-1} + b_{33}^2 h_{33,t-1} + 2b_{13}b_{23}h_{12,t-1} + 2b_{13}b_{33}h_{13,t-1} + 2b_{23}b_{33}h_{23,t-1} + d_{13}^2 v_{1,t-1}^2 + d_{23}^2 v_{2,t-1}^2 + d_{33}^2 v_{3,t-1}^2$$
$$+ 2d_{13}d_{23}v_{1,t-1}v_{2,t-1} + 2d_{13}d_{33}v_{1,t-1}v_{3,t-1} + 2d_{23}d_{33}v_{2,t-1}v_{3,t-1} + g_{33}^2 X_t \tag{6}$$

Data

We study three selected energy futures contracts that are traded on the New York Mercantile Exchange (NYMEX): crude oil, heating oil, and natural gas. Light sweet crude oil (WTI) futures contracts have expiry dates in every month of the year and are traded until the third business day prior to the 25th calendar day of the month preceding the delivery month. Standard contract size is 1,000 barrels and price is quoted as U.S. dollars and cents per barrel. Heating oil futures contracts also have expiry dates in all months of the year and are traded until the last business day of the month preceding the delivery month. Heating oil contract size is 42,000 gallons and price is quoted in U.S. dollars and cents per gallon. Natural gas (Henry Hub) futures contracts too have expiry dates in all months of the year and terminate trading three business days prior to the first day of the delivery month. Each contract stands for 10,000 million British thermal units (mmBtu) and quoted in U.S. dollars and cents per mmBtu. We construct price series for all three commodities by rolling over their first nearby contracts on the 15th day of expiration month (the month preceding the contract month). Futures price data are obtained from Commodity Research Bureau and Datastream provided by Thomson Reuters. Our sample covers the period from February 1, 1994 to February 4, 2011.

We study the impact of macroeconomic variables as well as major political or natural events on the volatility in energy markets. To this end, we use percentage changes in "Consumer Price Index for All Urban Consumers: All Items" and "Industrial Production Index," and the spread between the 10-year and 2-year "Treasury Constant Maturity Rate" obtained from Archival Federal Reserve Economic Data (ALFRED). ALFRED is released by the Economic Research Division of the Federal Reserve Bank of

St. Louis and contains data on major economic variables available at the time of the release (without any revisions made). All these variables are recorded monthly. We interpolate these monthly series via a step function to obtain daily series in order to use with our daily futures returns.

Because inventories play an important role in stabilizing demand and supply shocks for storable commodities we also include inventory data in our volatility analysis. Inventory data for all commodities are obtained from the U.S. Energy Information Administration (EIA). For crude oil, we use the "Weekly U.S. Ending Stocks of Crude Oil" series stated in thousand barrels. For heating oil, we use "Weekly U.S. Ending Stocks of Distillate Fuel Oil" stated in thousand barrels; and finally for natural gas, we use the series "Weekly Lower 48 States Natural Gas Working Underground Storage" stated in billion cubic feet. We compute percentage changes in inventories from one week to the next for each commodity and interpolate the resulting weekly series via a step function to obtain daily series to match the frequency with our price data.

Finally, dummy variables are used to account for the days of the week, calendar months, and political and weather-related events that affect the world price of crude oil. The day of Friday and the month of December are used as base categories and thus their effects are shown in the intercept. The discussion of the included events follows. (1) The Asian economic crisis that lasted from July 1997 to February 1998. This began with the collapse of the Thailand Baht and spread to many Asian countries. By late 1998, crude oil was priced at $8 per barrel and OPEC saw a need to have a shift in policy to restore oil prices to higher levels. For this event, our variable ASNFC takes the value of one on the dates between July 1, 1997 and February 28, 1998, and zero otherwise. (2) The pledge by

OPEC and non-OPEC countries to cut output by a combined of 2.104 million barrels per day. This event was a supply shock and hence directly increased the crude oil world price. The variable OPEC takes the value of one on the dates between March 23, 1999 and March 22, 2000, and zero otherwise. (3) The terrorist attacks on September 11, 2001. As a result of these attacks all market operations were halted and then resumed on September 17, 2001. However, this event changed the relationships with the Middle East permanently. The variable SEP11 takes the value of one on the date September 11, 2001 and thereafter. (4) The U.S. invasion of Iraq on March 19, 2003. It was reported that Iraq had launched missile attacks on Kuwait but there was no effect on any oil production facilities reported (The Financial Express, 2003). Our variable for this event named IRQINV takes the value of one on the dates between March 19, 2003 and April 17, 2003. (5) Hurricane Katrina hit the U.S. Gulf coast on August 29, 2005. Katrina was the costliest hurricane ever to hit the U.S. Gulf coast and the sixth strongest Atlantic hurricane event. Not only did this affect crude oil prices, but also natural gas prices. Katrina damaged or destroyed 30 oil platforms. Additionally, about nine refineries were forced to close down for the following six months, and the total loss in oil production in the Gulf coast was accounted for 24% of annual production. To account for this major event, the variable KTRN takes the value of one on the dates between August 29, 2005 and February 28, 2006, and zero otherwise. (6) The U.S. financial crisis became prevalent on September 15, 2008 when the major investment bank Lehman Brothers announced that it will be filing for bankruptcy. This caused many ripple effects as credit dried up in the financial markets, causing a credit constraint for firms and consumers. This would then cause a substantial decrease in demand for crude oil, gasoline, and other energy commodities. For this event, our variable LEHMN takes the value of one on the dates between September 15, 2008 and June 30, 2009.

Table 1 presents descriptive statistics of the daily futures returns and macro variables employed in the empirical analysis. Table 2 shows the unit root test results for futures price series. As can be seen in the table, both the levels and the logs of futures prices in all markets contain a unit root, that is, these series are nonstationary. However, we can reject the existence of a unit root for the return series, computed as the differences of log futures prices.

Empirical Results

For all three commodities we estimate a multivariate GARCH BEKK model with lagged returns included in the mean equations. Conditional variance equations include ARCH, asymmetric ARCH, and GARCH parameters as well as exogenous variables discussed earlier that might have an impact on volatility. In order to test whether upward changes in economic variables affect volatility differently than downward changes do, we include indicator variables for negative changes in consumer price index (CPI), industrial production index (IP), and inventories (INV). Table 3 presents the coefficient estimates and their p-values for the variance equations given in (4)-(6).

Crude Oil

The mean equation results show a constant return of 0.07 in crude oil futures. The first three lagged returns are significant, with a positive coefficient on the first lag and negative on the others. The constant conditional variance is 10.42. The ARCH parameter of 0.02 implies that positive disturbances (shocks, news) to crude oil increase conditional variance by that amount. However, past positive shocks to heating oil and natural gas volatility were found to be insignificant. The asymmetric ARCH coefficient for crude oil is 0.14, which means that past negative disturbances to crude oil increases the current conditional variance by 0.16. Additionally, negative shocks in heating oil markets are found to increase the conditional variance of crude oil by 0.13, showing spillover effects from heating oil to crude oil market. The GARCH parameter for crude oil is 0.91, showing that crude oil volatility in the past period has a large effect on volatility in the current period and is highly persistent. Lagged variance of natural gas returns is also found to increase the current variance of crude oil returns but by a very small amount.

Conditional variance results show that the structural change by OPEC, the September 11th terrorist attacks, the U.S. invasion of Iraq, hurricane Katrina, and the 2008 financial crisis which was elevated by the announcement of Lehman Brothers to file bankruptcy resulted in an increase in crude oil price volatility. These events increased the conditional variance by 1.18, 5.03, 1.73, 4.88, and 5.12 percent respectively. For the macro variables, positive and negative percent changes in CPI and heating oil inventories, the spread between the 10-year and 2-year Treasury bonds, and negative percent changes in natural gas inventories all have significant effects on the conditional variance of crude oil returns. For a one-percent increase in CPI, the conditional variance increases by 1.04 percent while for a one-percent decrease in CPI, the variance decreases by 9.08 percent. This could be the result of businesses seeing an opportunity to expand or produce more on lower energy prices, thus driving up the demand. Increased demand can be one factor that leads to higher price volatility, although it is not the only factor. As the spread between the 10-year and 2-year interest rates increases by one percent, crude oil futures return variance increases by 0.13 percent. Interestingly, the changes in crude oil inventories are not statistically significant. However, heating oil inventories are found to affect crude oil variance. For a one-percent increase in heating oil inventories, the conditional variance of crude oil increases by 0.04 percent and for a one-percent decline it decreases by 0.07 percent. Similarly, for a one-percent decrease in natural gas inventories, the conditional variance of crude oil decreases by 0.02 percent. These inventory effects are puzzling because one would expect higher crude oil volatility with lower heating oil or natural gas inventories. Crude oil variance is found to be higher on Mondays and Thursdays compared to the base category of Fridays. Interestingly volatility on Wednesdays is not higher than Fridays even though the U.S. Energy Information Administration releases the weekly inventory report on Wednesdays. Higher volatility on Mondays can be the result of any major news that may have taken place during the weekend. All monthly dummy variables except for January are found to be significant, showing higher volatility compared to December.

Heating Oil

Heating oil futures have a constant return of 0.08. Autocorrelation in the returns is found only in the first three lags. While the coefficient on the first lagged return is positive, the coefficients on the second and third lagged returns are negative. The constant conditional variance is 2.91. The ARCH parameter is 0.07 and statistically significant. There is significant but very small spillover effects from the crude oil market. The asymmetric ARCH term for heating oil is 0.03, which suggests that past negative news in the heating oil market increases the current conditional variance by 0.11. Both positive and negative disturbances to crude oil markets are also found to increase the variance of heating oil returns by 0.01 and 0.04, respectively. The GARCH parameter is 0.82, showing a high level of persistence. Additionally volatility spillover effect from both crude oil and natural gas markets to the heating oil market is found but the magnitude is small.

The Asian financial crisis and the structural change by OPEC are found to have significant impact on the conditional variance of heating oil futures. The heating oil variance increased by 2.66 due to Asian financial crisis in 1997, and increased by 0.56 after OPEC's quota cuts in 1999. Among the macro variables, both positive and negative changes in industrial production index and heating oil inventories, positive changes in CPI and the spread between the 10-year and 2-year Treasury bonds are found to be statistically significant. A one-percent increase in CPI increases the conditional variance by 4.11 percent. A one-percent increase in industrial production increases the conditional variance by 0.66, whereas a one-percent decrease in industrial production lowers it by 3.9. A one-percent increase in heating oil inventories raises the conditional variance by 0.04 and a-one percent decrease causes the conditional variance to decrease by 0.16. This is in contrast to what the theory of storage predicts. As the spread between the 10-year and 2-year Treasury bonds increases by one percent the conditional variance increases by 0.06. In terms of seasonality, only the months of September and November exhibit statistically higher volatility than the month of December. There are also significant day-of-the-week effects on volatility on Mondays and Wednesdays, with both being higher than the volatility on Fridays. Because heating oil inventory level reports are released by the U.S. Energy Information Administration along with the crude oil inventories, it is expected to have higher volatility on Wednesdays. However, the same Wednesday effect was not found for crude oil.

Natural Gas

The constant return for natural gas futures is 0.06 but it is insignificant. Autocorrelation is found in the first, the second, and the fifth lags of returns. The ARCH parameter of 0.05 suggests that past shocks in natural gas markets do increase the current variance by this amount. Interestingly, there were no significant asymmetric ARCH effects. The GARCH parameter is 0.13. Unlike crude oil and heating oil, this is significantly smaller and suggests that volatility in the natural gas market is not as persistent as in the other two markets. Further, there is a volatility spillover effect from heating oil to the natural gas market (0.06). This is the largest volatility spillover effect found in any of these energy markets and could be due to the fact that heating oil and natural gas are substitutes for residential and commercial heating.

Among the events considered only hurricane Katrina and the 2008 financial crisis significantly increased the conditional variance of natural gas by 8.94 and 8.29, respectively. As for the macro variables, a one-percent increase in the spread between the 10-year and 2-year Treasury bonds causes the conditional variance of natural gas to increase by 0.06. Only upward changes in crude oil inventories and negative changes in heating oil inventories are significant. Accordingly, the conditional variance of natural gas increases by 0.49 for a one-percent increase in crude oil inventories and decreases by 0.05 for a one-percent decrease in heating oil inventories. Interestingly, the changes in natural gas inventory levels do not affect the volatility of natural gas futures returns. All weekdays are found to exhibit higher volatility than Fridays. Volatility in the months of March through June is found to be higher than in December.

The bottom part of table 3 shows model diagnostic tests. The loglikelihood function value is -25,619.9. The Ljung-Box Q statistics show that we cannot reject the independence of the three standardized residual series obtained from this multivariate GARCH model at 10%. This shows that there is no autocorrelation left in the residuals and the model fits the data well. We also performed a likelihood ratio test to see whether the exogenous variables included in the variance equations add any value to the model. It is seen from the likelihood ratio test statistic and its p-value that we can reject the model with no exogenous variables.

Conclusions

This study investigates the determinants of high price volatility in energy futures markets, namely crude oil, heating oil, and natural gas, while accounting for asymmetric effects of news and possible spillover effects across the markets. Further, it analyzes the impact of major political and weather-related events and the main macroeconomic variables on the volatility in these markets.

Various spillover effects were found in each market, with some being bi-directional and some being unidirectional. Heating oil is found to be affected by the random shocks in its own market and in the crude oil market. Heating oil is a by-product of crude oil and therefore one would expect any shock in the crude oil market to have an effect on heating oil volatility. Volatility transmission from natural gas to the crude oil market is found. There is evidence of bi-directional volatility spillover effects between heating oil and natural gas, which is expected as they are substitutes For asymmetric effects, there was evidence of bi-directional spillovers between crude oil and heating oil. The impact of negative shocks in the heating oil market on crude oil variance is four times larger than the impact of negative shocks in the crude oil market on heating oil variance.

Volatility in energy markets is found to change in response to major events. The Asian financial crisis only increased the volatility of heating oil returns. OPEC's quota cuts in 1999 increased the volatility of both crude oil and heating oil, as one would expect, since this was a direct supply shock. The terrorist attacks on September 11, 2001 and the Iraq invasion in 2003 increased only the volatility of crude oil. Even though Iraq is part of the OPEC and its crude oil production is not counted, fears of destruction to oil facilities in the Middle East have probably caused the increased volatility. Hurricane Katrina dramatically increased both crude oil and natural gas volatility. The reason for such a high increase in volatility is that most of the crude oil and natural gas production facilities in the U.S. are situated in the Gulf Coast region.

Among the macroeconomic variables considered, the spread between the 10-year and 2-year Treasury bonds and negative changes in heating oil inventories affect the volatility of all three commodities. An increase in the Treasury bond spread implies a steeper yield curve, where the economy is expected to improve quickly. Since these commodities are inputs for businesses and their respective prices are correlated with the economy's performance, then faster economic growth would lead to greater demand and possibly higher price volatility. Positive changes in CPI have the strongest effect on heating oil volatility and this can be because this commodity is the most directly consumed energy product by consumers. One interesting result was that neither crude oil nor natural gas volatility is affected by their own inventory changes. A decrease in heating oil inventories is expected to increase crude oil volatility as heating oil is derived from crude oil and a shortage in heating oil would increase the demand for crude oil. Similarly, an increase in demand for natural gas would arise as a result of heating oil shortage. However, both crude oil and natural gas conditional variance decreased with a decrease in heating oil inventories.

Crude oil market is found to exhibit strong seasonality with higher volatility from February through November compared to December. Seasonality in other markets is not as strong as in crude oil. In terms of daily patterns, results vary among commodities. While natural gas volatility is higher on all other weekdays compared to Fridays, crude oil volatility is higher on Mondays and Thursdays and heating oil volatility is higher on Mondays and Wednesdays. This is interesting as the U.S. Energy Information Administration inventory reports are usually released on Wednesdays, so one would expect all commodities to have similar weekday patterns. Weekly natural gas inventory reports by the U.S. Energy Information Administration are issued on Thursdays, so higher volatility on that day is expected.

In recent months, there had been much debate on whether the U.S. Federal Reserve should continue its $600 billion quantitative easing program, termed QE2, which ended on June 30 2011. One impact of continuing such a program would be a possible increase in inflation through increasing the monetary base. As our results show changes in consumer price index have the strongest effect on crude oil and heating oil volatility. Thus, this can very well cause major discomfort for consumers. Additionally, if policy makers want to curb volatility in energy prices then lowering the spread between long- and short-term interest rates interest rates can be of use as the Treasury bonds spread is found to be positively related to the volatility of all three commodities. Lowering the spread can be achieved either increasing the short-term interest rates or lowering the long-term rates. This would not be very easy task as many financial firms currently depend on lower interest rates for many day-to-day operations in financial and commodity markets. In addition to adequate monetary policy, regulations are very much necessary to be created and/or enforced in order to prevent another financial calamity, as crude oil and natural gas volatilities were highly affected by the 2008 U.S. financial crisis.

References

Baillie, R.T., and R.P. DeGennaro. 1990. "Stock Returns and Volatility." Journal of Financial and Quantitative Analysis 25(2):203-214.

Baillie, R.T., and R.J. Myers. 1991. "Bivariate GARCH Estimation of the Optimal Commodity Futures Hedge." Journal of Applied Econometrics 6:109-124.

Bessembinder, H, and K. Chan. 1992. "Time-Varying Risk Premia and Forecastable Returns in Futures Markets." Journal of Financial Economics 32(2):169-193.

Bollerslev, T. 1986. "Generalized Autoregressive Conditional Heteroskedasticity." Journal of Econometrics 31(3):307-327.

Bollerslev, T. 1987. "A Conditionally Heteroskedastic Time Series Model for Speculative Prices and Rates of Return." The Review of Economics and Statistics 69:542-547.

Bollerslev, T., R.F. Engle, and J.M. Wooldridge. 1988. "A Capital Asset Pricing Model with Time-Varying Covariances." The Journal of Political Economy 96:116-131.

Brown, S.P., and M.K. Yucel. 2008. "What Drives Natural Gas Prices?" Energy Journal 29(2):45-60.

Chang, C., M. McAleer, and R. Tansuchat. 2010. "Analyzing and Forecasting Volatility Spillovers, Asymmetries and Hedging in Major Oil Markets." Energy Economics 32(6):1445-1455.

Elder, J., and A. Serletis. 2010. "Oil Price Uncertainty." Journal of Money, Credit & Banking (Wiley-Blackwell) 42(6):1137-1159.

Engle, R.F. 1982. "Autoregressive Conditional Heteroscedasticity with Estimates of the Variance of United Kingdom Inflation." Econometrica 50(4):987-1007.

Engle, R. F., & Kroner, K. F. (1995). Multivariate Simultaneous Generalized ARCH. Econometric Theory, 11(1):122-150.

Ewing, B.T., F. Malik, and O. Ozfidan. 2002. "Volatility Transmission in the Oil and Natural Gas Markets." Energy Economics 24(6):525-538.

French, K.R., G.W. Schwert, and R.F. Stambaugh. 1987. "Expected Stock Returns and Volatility." Journal of Financial Economics 19:3-29.

Geman, H., and S. Ohana. 2009. "Forward Curves, Scarcity and Price Volatility in Oil and Natural Gas Markets." Energy Economics 31(4):576-585.

Goodwin, B.K., and R. Schnepf. 2000. "Determinants of Endogenous Price Risk in Corn and Wheat Futures Markets." The Journal of Futures Markets 20:753-774.

Hamilton, J.D. 1983. "Oil and the Macroeconomy since World War II." Journal of Political Economy 91(2):228-248.

Hamilton, J.D., and A.Herrera. 2004. "Oil Shocks and Aggregate Macroeconomic Behavior: The Role of Monetary Policy." Journal of Money, Credit & Banking (Ohio State University Press) 36(2):265-286.

Hammoudeh, S., H. Li, and B. Jeon. 2003. "Causality and Volatility Spillovers among Petroleum Prices of WTI, Gasoline and Heating Oil in Different Locations." North American Journal of Economics & Finance 14(1):89-114.

Hartley, P.R., K.B. Medlock III, and J.E. 2008. Rosthal. "The Relationship of Natural Gas to Oil Prices." Energy Journal 29(3):47-65.

Kilian, L. 2008. "Exogenous Oil Supply Shocks: How Big Are They and How Much Do They Matter for the U.S. Economy?" Review of Economics and Statistics 90(2): 216-240.

Lanman, Scott, and Rich Miller. 2008. "Bernanke May Run Low on 'Ammunition' for Loans, Rates." Bloomberg. Bloomberg, 17 Mar 2008. Web. <http://www.bloomberg.com/apps/news?pid=newsarchive&sid=aOv1UfsECliU&refer=home>.

Lee, T.K., and J. Zyren. 2007. "Volatility Relationship between Crude Oil and Petroleum Products." Atlantic Economic Journal 35(1):97-112.

Lin, W., and C. Duan. 2007. "Oil Convenience Yields Estimated under Demand/Supply Shock." Review of Quantitative Finance & Accounting 28(2):203-225.

Mu, X. 2007. "Weather, Storage, and Natural Gas Price Dynamics: Fundamentals and Volatility." Energy Economics 29(1):46-63.

Myers, R.J. 1991. "Estimating Time-Varying Optimal Hedge Ratios on Futures Markets." The Journal of Futures Markets 11:39-53.

Myers, R.J., and S.D. Hanson. 1993. "Pricing Commodity Options when the Underlying Futures Price Exhibits Time-Varying Volatility." American Journal of Agricultural Economics 75:121-130.

Olowe, R.A. 2010. "Oil Price Volatility, Global Financial Crisis and the Month-of-the-Year Effect." International Journal of Business & Management 5(11):156-170.

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

Rahman, S., and A. Serletis. 2010. “The Asymmetric Effects of Oil Price and Monetary Policy Shocks: A Nonlinear VAR Approach.” Energy Economics 32(6):1460-1466.

Regnier, E. 2007. “Oil and Energy Price Volatility.” Energy Economics 29(3):405-427.

Serletis, A., and J. Herbert. 1999. “The Message in North American Energy Prices.” Energy Economics 21(5):471-483.

Serletis, A., and R. Rangel-Ruiz. 2004. “Testing for Common Features in North American Energy Markets.” Energy Economics 26(3):401-414.

Suenaga, H., A. Smith, and J. Williams. 2008. “Volatility Dynamics of NYMEX Natural Gas Futures Prices.” J. Futures Mkts. 28:438–463.

Yang, S.R., and B.W. Brorsen. 1993. “Nonlinear Dynamics of Daily Futures Prices: Conditional Heteroskedasticity or Chaos?” The Journal of Futures Markets 13(1):175-191.

Zagaglia, P. 2010. “Macroeconomic Factors and Oil Futures Prices: A Data-Rich Model.” Energy Economics 32(2): 409-417.

Table 1. Summary Statistics

Variable	Mean	Standard Deviation	Minimum	Maximum
Crude Oil Return	0.040	2.337	-16.544	18.444
Heating Oil Return	0.038	2.227	-13.965	10.297
Natural Gas Return	0.012	3.542	-21.617	32.586
% Δ Consumer Price Index	0.175	0.355	-1.700	1.100
% Δ Industrial Production Index	0.110	0.616	-2.800	1.700
Treasury Bond Spread	1.019	0.939	-0.410	2.830
% Δ Crude Oil Inventories	0.022	0.413	-1.430	1.513
% Δ Heating Oil inventories	-0.017	1.841	-8.440	5.730
% Δ Natural Gas Inventories	0.155	4.771	-17.357	12.346

Notes. Sample period is 02/01/1994-02/04/2011 and total number of observations is 4276. Returns are calculated as r_t=100x(ln F_t - ln F_{t-1}), where F_t is daily settlement price of the futures contract on day *t*. Treasury bond spread is calculated as the difference between the 10-year and 2-year Treasury constant maturity rate and stated in percent. All economic variables are interpolated via a step function to obtain daily series to use with the daily return data.

Table 2. Augmented Dickey-Fuller Unit Root Tests

Variable	τ	p-value
Futures Prices		
F_{CL}	-0.91	0.7851
F_{HO}	-0.62	0.8642
F_{NG}	-2.45	0.1285
Log of Futures Prices		
ln F_{CL}	-1.04	0.7414
ln F_{HO}	-0.70	0.8460
ln F_{NG}	-2.11	0.2418
Futures Returns		
r_{CL}	-48.75	<0.0001
r_{HO}	-47.38	<0.0001
r_{NG}	-47.31	<0.0001

Notes. The τ statistics and their p-values are presented for single-mean Augmented Dickey-Fuller unit root test with one lag. CL, HO, and NG refer to crude oil, heating oil, and natural gas, respectively. Futures returns are calculated as r_t=100x(ln F_t - ln F_{t-1}).

Table 3. GARCH-BEKK Results

Mean Eq.	CL	HO	NG			
Constant	0.072	0.080	0.061			
	(0.000)	(0.000)	(0.181)			
R_{t-1}	0.037	0.032	-0.030			
	(0.000)	(0.000)	(0.022)			
R_{t-2}	-0.044	-0.040	-0.022			
	(0.000)	(0.000)	(0.043)			
R_{t-3}	-0.031	-0.031	-0.004			
	(0.000)	(0.000)	(0.703)			
R_{t-4}	-0.010	-0.001	0.015			
	(0.210)	(0.901)	(0.217)			
R_{t-5}	-0.001	0.001	-0.024			
	(0.858)	(0.830)	(0.056)			
Variance Eq.	**Var (CL)**	**Var(HO)**	**Var (NG)**	**Cov (CL,HO)**	**Cov (CL,NG)**	**Cov (HO,NG)**
Constant	10.417	2.913	2.702	5.416	-5.187	-2.804
	(0.000)	(0.017)	(0.000)	(0.000)	(0.000)	(0.000)
$u^2_{1,t-1}$	0.020	0.007	0.003	-0.012	-0.008	0.005
	(0.003)	(0.038)	(0.549)	(0.000)	(0.241)	(0.250)
$u^2_{2,t-1}$	0.002	0.074	0.002	0.014	0.002	0.013
	(0.333)	(0.000)	(0.656)	(0.086)	(0.414)	(0.375)
$u^2_{3,t-1}$	0.000	0.000	0.045	0.000	-0.003	-0.002
	(0.543)	(0.533)	(0.000)	(0.526)	(0.218)	(0.206)
$u_{1,t-1}u_{2,t-1}$	0.014	-0.045	-0.005	0.035	0.004	-0.019
	(0.010)	(0.001)	(0.584)	(0.000)	(0.551)	(0.242)
$u_{1,t-1}u_{3,t-1}$	-0.003	0.002	-0.024	0.000	0.031	-0.017
	(0.230)	(0.228)	(0.238)	(0.441)	(0.000)	(0.000)
$u_{2,t-1}u_{3,t-1}$	-0.001	-0.006	0.020	-0.004	0.010	0.057
	(0.365)	(0.226)	(0.373)	(0.244)	(0.068)	(0.000)
$h^2_{11,t-1}$	0.908	0.001	0.000	0.033	0.016	0.001
	(0.000)	(0.067)	(0.811)	(0.000)	(0.632)	(0.632)
$h^2_{22,t-1}$	0.000	0.816	0.064	-0.025	-0.007	0.228
	(0.253)	(0.000)	(0.003)	(0.019)	(0.037)	(0.000)
$h^2_{33,t-1}$	0.004	0.002	0.134	0.003	0.024	0.018
	(0.000)	(0.004)	(0.000)	(0.000)	(0.000)	(0.000)
$h_{12,t-1}$	-0.052	0.062	0.008	0.860	0.241	0.024
	(0.024)	(0.000)	(0.611)	(0.000)	(0.000)	(0.436)
$h_{13,t-1}$	0.127	0.003	0.012	0.049	0.350	0.013
	(0.000)	(0.005)	(0.631)	(0.000)	(0.000)	(0.001)
$h_{23,t-1}$	-0.004	0.088	0.185	0.059	0.007	0.343
	(0.063)	(0.000)	(0.000)	(0.000)	(0.145)	(0.000)

Variance Eq.	Var (CL)	Var(HO)	Var (NG)	Cov (CL,HO)	Cov (CL,NG)	Cov (HO,NG)
$v_{1,t-1}^2$	0.140	0.032	0.013	0.067	-0.042	-0.020
	(0.000)	(0.033)	(0.619)	(0.002)	(0.324)	(0.316)
$v_{2,t-1}^2$	0.127	0.034	0.017	0.066	-0.046	-0.024
	(0.000)	(0.090)	(0.604)	(0.013)	(0.299)	(0.287)
$v_{3,t-1}^2$	0.001	0.001	0.006	0.001	0.003	0.002
	(0.348)	(0.421)	(0.518)	(0.373)	(0.325)	(0.340)
$v_{1,t-1}v_{2,t-1}$	-0.267	-0.067	-0.029	-0.133	0.089	0.044
	(0.000)	(0.047)	(0.601)	(0.003)	(0.297)	(0.285)
$v_{1,t-1}v_{3,t-1}$	0.026	0.011	-0.017	0.017	0.025	0.011
	(0.064)	(0.130)	(0.439)	(0.090)	(0.268)	(0.372)
$v_{2,t-1}v_{3,t-1}$	-0.025	-0.011	0.020	-0.017	-0.023	-0.011
	(0.087)	(0.179)	(0.372)	(0.121)	(0.310)	(0.431)
CPI	1.044	4.105	0.008	-1.163	-0.056	0.183
	(0.039)	(0.001)	(0.879)	(0.045)	(0.771)	(0.750)
CPI*I^-	8.032	1.077	2.388	-2.097	-3.940	1.408
	(0.002)	(0.411)	(0.186)	(0.250)	(0.011)	(0.234)
IP	0.097	0.660	0.000	0.204	0.000	0.001
	(0.241)	(0.042)	(0.997)	(0.181)	(0.994)	(0.994)
IP*I^-	0.580	3.272	0.393	-1.148	-0.399	1.134
	(0.152)	(0.048)	(0.268)	(0.086)	(0.166)	(0.018)
TSPRD	0.130	0.061	0.062	0.088	-0.089	-0.061
	(0.021)	(0.096)	(0.015)	(0010)	(0.001)	(0.007)
INV CL	0.026	0.404	0.489	0.096	0.101	0.443
	(0.636)	(0.182)	(0.027)	(0.431)	(0.448)	(0.020)
INV CL*I^-	0.522	1.501	0.043	-0.646	-0.119	0.254
	(0.245)	(0.175)	(0.701)	(0.199)	(0.453)	(0.466)
INV HO	0.038	0.043	0.001	-0.016	-0.003	0.006
	(0.004)	(0.073)	(0.615)	(0.188)	(0.345)	(0.331)
INV HO*I^-	0.031	0.116	0.045	-0.026	-0.021	0.069
	(0.070)	(0.070)	(0.002)	(0.352)	(0.228)	(0.004)
INV NG	0.001	0.001	0.000	0.000	0.000	0.000
	(0.201)	(0.261)	(0.874)	(0.965)	(0.880)	(0.844)
INV NG*I^-	0.015	0.011	0.000	-0.001	0.000	0.002
	(0.015)	(0.122)	(0.801)	(0.747)	(0.660)	(0.606)
ASNFC	0.091	2.666	0.635	0.387	-0.198	-1.296
	(0.589)	(0.018)	(0.287)	(0.492)	(0.419)	(0.091)
OPEC	1.180	0.560	0.023	0.733	-0.152	-0.112
	(0.025)	(0.074)	(0.691)	(0.012)	(0.391)	(0.426)
SEP11	5.026	0.278	0.158	1.179	0.889	0.210
	(0.000)	(0.234)	(0.157)	(0.014)	(0.008)	(0.094)
IRQINV	1.726	0.249	1.638	0.243	0.175	0.575
	(0.054)	(0.623)	(0.106)	(0.332)	(0.701)	(0.382)
KATRN	4.880	1.381	8.943	-2.556	6.593	-3.490
	(0.005)	(0.133)	(0.009)	(0.002)	(0.000)	(0.010)
LEHMN	5.116	0.051	8.293	-0.470	-6.394	0.634
	(0.007)	(0.883)	(0.018)	(0.792)	(0.000)	(0.778)

Variance Eq.	Var (CL)	Var(HO)	Var (NG)	Cov (CL,HO)	Cov (CL,NG)	Cov (HO,NG)
Mon	0.334	1.168	3.042	0.495	0.725	1.861
	(0.093)	(0.015)	(0.000)	(0.043)	(0.040)	(0.000)
Tue	0.008	0.074	0.230	-0.006	0.007	-0.130
	(0.602)	(0.471)	(0.077)	(0.899)	(0.928)	(0.169)
Wed	0.089	0.306	0.247	-0.121	0.095	-0.260
	(0.253)	(0.099)	(0.059)	(0.200)	(0.231)	(0.013)
Thu	0.451	0.008	1.581	-0.059	0.826	-0.108
	(0.067)	(0.845)	(0.000)	(0.699)	(0.000)	(0.707)
Jan	0.250	0.583	0.025	-0.231	0.064	-0.112
	(0.293)	(0.310)	(0.664)	(0.369)	(0.488)	(0.437)
Feb	1.989	0.162	0.243	-0.510	-0.649	0.196
	(0.010)	(0.568)	(0.229)	(0.271)	(0.021)	(0.334)
Mar	3.706	0.535	1.311	-1.384	-2.165	0.838
	(0.000)	(0.273)	(0.007)	(0.028)	(0.000)	(0.053)
Apr	4.725	0.626	3.936	-1.656	-4.172	1.569
	(0.000)	(0.263)	(0.000)	(0.024)	(0.000)	(0.034)
May	1.822	0.449	1.705	0.402	1.668	-0.622
	(0.011)	(0.209)	(0.009)	(0.395)	(0.000)	(0.219)
Jun	3.341	0.667	1.618	-1.476	-2.276	1.037
	(0.000)	(0.354)	(0.042)	(0.069)	(0.000)	(0.146)
Jul	2.326	0.026	0.347	-0.218	-0.896	0.081
	(0.009)	(0.818)	(0.148)	(0.714)	(0.011)	(0.731)
Aug	1.621	0.510	0.033	0.892	-0.220	-0.129
	(0.030)	(0.326)	(0.626)	(0.073)	(0.339)	(0.372)
Sep	3.232	2.999	0.077	3.110	0.498	0.480
	(0.014)	(0.018)	(0.616)	(0.002)	(0.305)	(0.300)
Oct	3.009	1.533	0.135	2.135	0.632	0.456
	(0.007)	(0.126)	(0.295)	(0.007)	(0.057)	(0.076)
Nov	1.853	2.232	0.209	1.975	-0.596	-0.680
	(0.030)	(0.032)	(0.289)	(0.004)	(0.047)	(0.058)
LLF	-25619.9					
LR	883.793					
	(0.000)					
Lyung-Box Q	52.015	42.346	32.712			
	(0.096)	(0.370)	(0.787)			

Notes. The transformed coefficients on each term in the variance and covariance equations and their p-values are presented. LLF refers to loglikelihood function value. Likelihood ratio (LR) test statistics and its p-value for the null hypothesis of no exogenous variables in variance equations are given. Lyung-Box Q statistics and their p-values for the test of independence of the model residuals are presented.