How does the Crude Oil Market Impound Inventory News Information? A Closer Look at High-frequency Prices and Trading Activities

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Abstract

We empirically study how the crude oil market impounds inventory news information. Using 5-minutes intraday high frequency data of crude oil futures, we examine the response of crude oil futures market to the crude oil inventory report released by U.S. Energy Information Administrations (EIA) on every Wednesday at 10:30AM Eastern Time. Applying inference technique of Jump Predictor Test (JPT), we find that consistently with the Efficient Market Hypothesis (EMH), the crude oil inventory announcement significantly increases the likelihood of jumps at the announcement and in the immediate subsequent periods. Similarly, this announcement also significantly increases the intraday volatility and trading activities in the same periods. Besides, other major market news, e.g., Nonfarm Payroll Report and Natural Gas Inventory Report, are also found to trigger jumps in crude oil futures market, while only the Nonfarm Payroll Report has substantial impact on intraday volatilities and trading activities. Also consistently with the EMH, we find that inventory shock does not predict the nearby futures price return after the announcement. However, the inventory shock has explanatory power on basis change of longer maturity futures after the announcement, casting doubt on the EMH. To our surprise, we document evidence that the crude oil inventory shock has explanatory power on the nearby futures price return and the basis changes of longer maturity futures in the period prior to the announcement, implying occurrence of information leakage in crude oil futures market. Furthermore, we find a negative contemporaneous relation between jump component of volatility and trading volumes on Wednesday during recession time (2008 ~ 2010), raising doubt on the Mixed Distribution Hypothesis (MDH) in the presence of public information such as crude oil inventory announcement. Finally, we estimate the daily change of risk neutral model-free jump variance (RNJV) implied by option market, and find no evidence that the option market can "foresee" the jumps in crude oil futures price induced by the crude oil inventory announcement.

Keywords: inventory; economic news; jump; market efficiency; crude oil futures; volatility; trading volume; risk-neutral jump variance

JEL Classification: G12, G13, G14

1 Introduction

Inventory is one of the fundamental determinants of commodity futures prices.[1] In practice, market participants closely watch the news on inventory and adjust their positions when new information hits on market. Every Wednesday at 10:30AM (Eastern Time; ET, hereafter)[2], Energy Information Administration (EIA, hereafter) releases the report of weekly inventory of crude oil, which attracts most attentions from market participants. Not surprisingly, EIA's inventory announcement has a sizable influence on crude oil futures prices: One folklore circling among traders is that the futures market often exhibits price jumps at announcement. A few relatively recent papers study the impact of inventory announcement on price movement and volatility (Linn and Zhu (2003); Halva et al. (2013); Chiou-Wei et al. (2014); Rosenman and Wolfe (2014) among others). However, answers for several empirical questions, which are important in coherent understanding of how the crude oil market impounds inventory news information, are still remain unclear: (1) How likely would the inventory announcement trigger jumps at the announcement time and in the immediate subsequent period? (2) How does the inventory announcement affect intraday volatilities and trading activities? (3) Does an inventory shock influence a commodity price and futures basis *only* after the announcement? (4) Given the fact that realized volatility has both the jump part and the continuous part, does the inventory announcement influence the widely documented positive contemporaneous relation between volatilities and trading volume? (5) Does the options market contain forward-looking information to "predict" the jumps which will be induced by the inventory announcement?

In this paper, to understand how the crude oil market impound inventory news release information, we empirically examine the effect of inventory news on commodity price jump, return volatility, and trading activities, using 5-minutes intraday high frequency crude oil futures price data and options data of the nearby futures contract spanning the period July 1, 2003 through Dec 31, 2011.[3] Our major findings are: First, consistently with the Efficient Market Hypothesis (EMH, hereafter), our Jump Predictor Test (JPT, hereafter; Lee, 2012) results show that the inventory announcement increases the odds of jump arrivals at announcement (10:35AM Wednesday) and in the immediate subsequent period (10:35AM to 11:00AM Wednesday) by a factor of 42.2 and 6.58, respectively. Similarly, the announcement also increases the intraday volatility (annualized) and number of trades in the same period by 15.6% and 2104, respectively. Moreover, our JPT test results show that several other announcements (i.e., Natural Gas Inventory Report and Non-farmer Payroll Report) also significantly increase the likelihood of jumps in crude oil market, providing evidence for a potential channel for the co-movement of volatilities between crude oil market and other markets. On the other hand, we find that only the

[1] Inventory is the key variable in two major theories explaining futures price. In the Theory of Storage (Kaldor (1939), Working (1949)), inventory is closely related to convenience yield. In the Theory of Normal Backwardation ((Keynes (1930), Hicks (1939), Hirshleifer (1990) and Gorton et al. (2012)), inventory level directly affects the risk premium embed in futures price.

[2] All timestamps in this paper are in Eastern Time.

[3] Our option data is from July 1, 2003 to Dec 31, 2010.

Non-farmer Payroll Report has substantial impact on intraday volatilities and trading activities in crude oil market. Second, we find evidence of inventory information leakage prior to announcement (10:00AM to 10:30AM Wednesday) and evidence that the inventory shock has explanatory power to explain the basis changes of longer maturity futures in the period after the announcement (10:35AM to 11:00AM Wednesday. Third, after decomposing the realized volatility into integrated and jump components, we find significantly negative contemporaneous relation between jump volatilities and trading volumes on Wednesday, which is opposite to the widely documented evidence. Fourth, by estimating the change of model-free implied jump variance (RNJV, hereafter) between Tuesday and Wednesday, we find that the option market on Tuesday does not "predict" that more jumps would occur on Wednesday due to the scheduled inventory announcement.

Estimating the likelihood that the inventory announcement would trigger jumps in crude oil futures price is not only of great interest to practitioners, but also of theoretical importance as it provides insights into modeling volatility behavior and has deep implications for option pricing in crude oil market. Our work is related to Elder et al. (2013) who examine the 5-minute interval intraday data of crude oil futures and find that a large proportion of the largest jumps at 10:35AM are preceded by the inventory announcement. However, they do not perform a formal statistical inference on the linkage between the identified jumps and the inventory announcement, and therefore are silent about the incremental stochastic jump intensity. In contrast, we draw inference on the latent jump intensity by applying the JPT in a similar way as Lee (2012) does to investigate the predictability of jumps in U.S. stock market. Specifically, we use the nonparametric jump statistic developed by Lee and Mykland (2008) to identify jumps in futures price, and then perform the JPT on a list of jump predictor candidates, including inventory announcement. To the best of our knowledge, we are the first to apply the JPT to commodity futures market. In addition, we investigate jumps not only at 10:35AM but also at subsequent periods in order to gain insights into the speed that inventory information is impounded to crude oil futures prices.

Partitioning each day-session (8:00AM to 2:30PM) into 13 consecutive intraday periods, we investigate the extent to which the crude oil inventory announcement affects intraday volatilities and trading activities on announcement days. We find that the announcement increases the annualized volatility (number of trades) in the immediate subsequent period after the announcement (10:30AM – 11:00AM on Wednesday) by 17.6% (2104), while the triggered "chaos" quickly cool off in succeeding periods. Interestingly, we document evidence that both intraday volatilities and trading activities in periods prior to the announcement are significantly lower relative to other weekdays. Our findings are consistent with work by Jubinski and Tomljanovich (2013), who study the influence of the release of the Federal Reserve minutes on equity market, and document evidence that intraday volatility is lower prior to the minutes release and higher after the minutes release on release days. We also investigate such impact by other major market news, and find that only the Non-famer Payroll Report imposes substantial influence on intraday volatilities and trading activities on its report days.

We examine the EMH in crude oil futures market in the presence of inventory announcement, which is one of the most important public information in commodities market. According to Fama et al. (1965), in an efficient market, public news only affects market and be fully impounded in prices when news gets announcement. Two direct implications from the EMH are: (1) The shock from the scheduled news should not affect the market price ahead of the announcement unless information leaks; (2) once news gets out, there are no opportunities to make excess return by trading on public information. Accordingly, we test the following hypothesis: *The surprise of inventory announcement should have no power to explain the return of crude oil futures in period either before or after the announcement in crude oil market*. To this end, we run regression of the returns on shocks of inventory, which is defined as the difference between the realized inventory level and the best forecast by market (using the median of the inventory survey drawn from a few highly reputed analysts as a proxy).. After controlling for other variables affecting crude oil futures return (short rate, yield spread, basis and lagged return and variance), we find that the inventory shock has no power to explain the return in the subsequent period after announcement (10:35AM to 11:00AM Wednesday) as well as in the remaining period (11:00AM to 3:00PM Wednesday), which is consistent with our null hypothesis. However, to our surprise, we find some evidence that the explanatory power of inventory shock on return in period prior to announcement (10:00AM to 10:30AM Wednesday) and in preceding overnight (3:00PM Tuesday to 10:00AM Wednesday) becomes statistically significant at the 1% and 5% level respectively, indicating that the information leakage may occur prior to EIA inventory announcement. Interestingly, the period immediately before the announcement is not associated with frequent jumps, a finding indicating that if the inventory information is leaked, it may be leaked to only a small portion of the traders.

Existing theories of commodity futures suggest that a positive (negative) inventory shock increases (decreases) a futures basis, defined as price difference between futures and spot. As a further examination of the EMH, we investigate how crude oil futures basis change with respect to the inventory shock. We test the following hypothesis: *The surprise of inventory announcement should have no power to explain basis change in period either before or after the announcement in crude oil market*. Specifically, we use the nearby futures contract as our proxy of spot, and compute the basis for next 9 near futures with maturity up to 1 year. We run univariate regressions of basis change, realized in different periods, on inventory shock. Consistent with existing theories of commodity futures, we document strong positive correlation between the inventory shock and the basis change of all considered longer maturity futures in the period spanning the announcement (10:25AM to 10:35AM on Wednesday). We also find evidence to support information leakage prior to the announcement: the inventory shock has explanatory power on basis change of some longer maturity futures in the period prior to the announcement (9:00AM to 10:20AM on Wednesday). To our surprise, we find that, for the period after the announcement (10:35AM to 11:00AM on Wednesday), the slope coefficients of inventory shock of some longer maturity futures are statistically significant but negative. One explanation is that, unlike the nearby futures whose price immediately impounds inventory shock at 10:35AM, the longer maturity futures demonstrate a gradual response to the shock. Therefore, the basis changes of longer maturity futures at 10:35AM due to inventory shock appear to be "overshooting", and then revert back to the "right" level in succeeding periods. This finding casts doubt on crude oil market's efficiency as a whole. ext, this paper investigates whether inventory announcement has influence on the contemporaneous relationship between trading volumes and return volatility in crude oil futures market. The literature on this topic is extensive. Early empirical works[4] widely document a positive contemporaneous relation between the two[5], consistently with the Mixed Distribution Hypothesis (MDH, hereafter), which argues that both volatility and volume are jointly dependent on a common latent variable – the information flow. Three recent papers examine this stylized fact in an intraday high-frequency granularity: Giot et al. (2010) study the 100 largest stocks traded on NYSE, and find that only the continuous volatility component shows a positive contemporaneous volume-volatility relation, while the relation for jump volatility component is negative. Wang and Huang (2012) study the Chinese stock market and find the same. In contrast, Chevallier and Sevi (2012) find a positive contemporaneous relation between trading volume and jump volatilities in crude oil futures market. To reconcile these seemingly contradictory results, we propose an alternative potential explanation: Only jumps triggered by public information generate negative contemporaneous relations between trading volumes and jump volatilities. The rationale is that some market participants may trade *less* in the presence of jump triggered by public news because they agree that the market is right in interpreting the public news. We find empirical support for our explanation by examining the contemporaneous relation between trading volumes and jump volatilities on Wednesday, when a large proportion of jumps are triggered by public news - inventory announcement. Specifically, we disentangle the jump volatilities from realized volatilities obtained with intraday data of crude oil futures, and adopt the same regression specification as in Chevallier and Sevi (2012). We find significantly negative relation between trading volumes and jump volatilities on Wednesday in recession time (2008 to 2010), while no such effect can be found on other weekdays.

Option market is inherently forward looking, and may contain information on the future state of world (Chang et al., 2012). It is natural to ask if options on crude oil futures can foresee that more jumps would occur on Wednesday induced by the inventory announcement. In this paper, we utilize the methodology developed by Du and Kapadia (2011) to estimate the sample average change of model-free implied jump variance (RNJV, hereafter) between Tuesday and

[4] Examples include Karpoff (1987), Gallant et al. (1992), Andersen (1996), Ane et al. (2000) and among others.
[5] The mixture of distributions hypothesis (Clark (1973); Epps and Epps (1975); Tauchen and Pitts (1983); Harris (1987)) has long been used to explain the presence of the positive contemporaneous relation. According to this hypothesis, the volume and volatility are jointly dependent on a comment latent variable – the arrival of information, and the dissemination of information is contemporaneous.

Wednesday. Specifically, we take difference between the model-free implied variance of holding period return (Bakshi, Kapadia and Madan, 2003) and the model-free implied integrated variance (Carr and Wu, 2009) to construct the RNJV, and all these metrics can be estimated using set of OTM European Options. We test the following hypothesis: *Under the null hypothesis that option prices can "predict" inventory announcement effect, one should see, on average, abnormal change of RNJV between Tuesday and Wednesday*. We reject the null hypothesis with the results showing negligible change of RNJV between Tuesday and Wednesday for the sample period from July 1, 2003 to Dec 31, 2010.

This paper makes three contributions to literature. First, we complement papers studying the role of inventory in commodities market. For example, Gorton et al. (2012) argue that the inventory is the major determinant for futures risk premium across commodities; Rouwenhorst and Tang (2012) argue that historical data are more consistent with the Theory of Storage than the Theory of Normal Backwardation. Findings in this paper suggest that the market participants process such important inventory information relatively promptly and rationally. We provide the first rigorous verification in crude oil futures market that the inventory announcement statistically and economically significantly increases the stochastic jump intensity not only at announcement and but also in the immediate subsequent period. Also consistently with the EMH, we find that inventory shock does not predict the high-frequency futures return after the announcement. However, to our surprise, we find strong evidence for the news information leakage 30 minutes before the announcement.

Second, we shed light on the contemporary relationship between volatility and trading volume by proposing an alternative explanation for the relation between jump volatility and volume and documenting evidence from crude oil futures market. Differently from the MDH, we argue that in the presence of public news announcement, such a positive correlation may not be true because some traders trade less in the presence of jumps induced by public news if they believes the market is informationally efficient and agree on the market price. The crude oil market is an excellent laboratory to study this type of explanation because the most important public information, inventory news, is periodically released.

Third, our work contributes to the literature on option implied information. It is well known that the (model-free) option implied variance predicts the realized variance. Then, does the "option implied jump" predict the realized jump? To address this question, we introduce RNJV in predictive study on jumps in crude oil futures market, where inventory news-driven price jumps are expected to occur periodically, and do not find evidence that crude oil option prices contain forward looking information of jumps.

The rest of this paper is organized as follows. Section 2 introduces empirical measurements employed in our study. Section 3 develops empirical hypotheses. Section 4 discusses the data. Section 5 presents the empirical results and discusses the major findings. Section 3 concludes.

2 Hypothesis Development

2.1 Hypothesis on Efficient Crude Oil Futures Market

Fama et al. (1965) illustrate a classic graph of how stock prices react to new information in an efficient market: Prior to the announcement, the stock price fluctuates as investors are uncertain of the shock in the announcement; at the announcement, the price exhibits an instant jump as the realized shock is fully and immediately impounded in a price; after the announcement, there should be no opportunities for investors to make excess return by trading on the news. In a study of the impact of Federal Reserve interest rate target announcement on stock market, Figlewski et al. (2010) argue that market becomes more volatile after announcement until finding new equilibrium because market's response to news generate additional information to be digested. But, they find that the market is still informational efficient: the one-minute returns during the shock digesting period are uncorrelated.

If the EMH holds, the shock of crude oil inventory should be immediately impounded in crude oil futures price at the announcement. It follows that a large price change (jump) will occur when the shock is beyond market's ex-ante expectation, which is usually the case because the inventory shock is unpredictable:

> **H1a**: *Under EMH, a jump in crude oil futures price is more likely taking place at inventory announcement.*

In line with Figlewsi's argument, the crude oil futures market will be a lot more volatile in the immediate subsequent period, and more jumps will be observed during this period:

> **H1b1**: *Under EMH, one should, on average, observe more jumps in crude oil futures price in the immediate subsequent period after crude oil inventory announcement*

> **H1b2:** *Under EMH, one should, on average, observe higher volatility in crude oil futures price in the immediate subsequent period after crude oil inventory announcement*

> **H1b3:** *Under EMH, one should, on average, observe more trading activity in crude oil futures in the immediate subsequent period after crude oil inventory announcement*

Assuming that the EMH holds, there are no opportunities for investors to make excess return by trading the inventory shock after the announcement, and the shock of crude oil inventory should not affect market price before the announcement unless there is information leakage:

> **H1c1**: *Under EMH, the shock of crude oil inventory should have no power to explain the return of crude oil futures in period after the announcement;*

> **H1c2**: *Under EMH, the shock of crude oil inventory should have no power to explain basis change of crude oil futures realized in period after the announcement;*

> **H1d1:** *Under EMH, the shock of crude oil inventory should have no power to explain the return of crude oil futures in period prior to the announcement.*

> **H1d2:** *Under EMH, the shock of crude oil inventory should have no power to explain basisi change of crude oil futures realized in period prior to the announcement.*

2.2 Hypothesis on Contemporaneous Volatility-Volume Relation

In the literature, the widely documented positive contemporaneous relation between volatility and trading volumes is usually explained by the MDH, which argues that both volatility and volume are jointly dependent on a common latent variable – the information flow, and the dissemination of information is contemporaneous. If the MDH holds and jumps are driven by economic fundamentals, it must also holds for both continuous component and jump component part of volatility. Thus, we develop two hypotheses**:**

> **H2a***: One should observe a positive contemporaneous relation between the continuous component of volatility and trading volumes*;

> **H2b**: *One should observe a positive contemporaneous relation between the jump component of volatility and trading volumes*.

2.3 Hypothesis on Option Market's Predictability on Jumps

The RNJV contains option market's forward looking of jumps in state of future. If players in option market on crude oil futures are more capable to forecast or have different access to the crude oil inventory, the option prices should reflect this. In the case the option market on Tuesday "knows" that more jumps would be induced by crude oil inventory announcement the next day, the RNJV implied by options at the end of Tuesday should be noticeably larger than that implied by options at the end of Wednesday:

H3: *Under null hypothesis that option market can "predict" jumps induced by inventory announcement, one should see, on average, abnormal change of the RNJV between Tuesday and Wednesday.*

3 Empirical Measurements

3.1 Volatility Measure

Literature (e.g., Andersen and Bollerslev (1998a); Andersen et.al (2001); Barndorff-Nielsen and Shephard (2002)) has documented that the sum of squared intraday returns provides an accurate estimation of realized variance. Following this approach, we measure the realized variance for day t (or one sub-period within day t) by:

(1) $$RV_t = \sum_{j=1}^{M} \ln^2(P_{t,j}/P_{t,j-1}) \qquad t = 1, \dots, T$$

where M is the number of equally-spaced sub-intervals at the beginning and end of which prices are sampled, M+1 is the number of sampled observations in the period, and $P_{t,j}$ is j^{th} sampled observation of price. In the absence of microstructure noise, RV_t converges to the latent realized variance as the number of sampled observations goes to infinity. However, too high sampling frequency (too small width of sampling sub-intervals) may suffer from a serious bias induced by the microstructure noise. (See Hansen and Lunde (2006) for further discussion.) Hence, one needs to use the highest sampling frequency that the noise does not decrease the accuracy of the realized variance estimation. Specifically, we use 5 minutes as the sampling frequency because the 5-minute intervals are widely used in literature, and volatility signature plots (Hansen and Lunde (2006)) of high-frequency crude oil futures prices support this choice.

3.2 Volatility Decomposition

Let the logarithm of price $\ln(P_t)$ follow a diffusion process with jumps:

(2) $$d(\ln(P_t)) = u(P_t, t)dt + \sigma(P_t, t)dW(t) + \gamma(P_t, t)dM(t)$$

where $u(P_t, t)$ is the drift process, $\sigma(P_t, t)$ is the instantaneous volatility process, $\gamma(P_t, t)$ represents the size of jumps, and $M(t)$ is a counting process. The total variance, defined as the limit of the summation of squared log-returns in continuous time, is:

(3) $$Total\ Variance = \int_0^t \sigma^2(P_t, s)ds + \sum_{i=1}^{N(t)} \gamma^2(P_t, t).$$

where $N(t)$ is the number of jump occurrences between 0 and t. The first term in the right hand side represents the integrated variance or the variance contributed by a diffusion process, and the second term represents the jump variance contributed by a jump process. The summation in (1) is the sample counterpart of the total variance in (3). Rewrite (1) to:

(4) $RV_t = \sum_{j=1}^{M} \ln^2(P_{t,j}/P_{t,j-1}) \times (1 - I(jump\ at\ j)) + \sum_{j=1}^{M} \ln^2(P_{t,j}/P_{t,j-1}) \times I(jump\ at\ j)$

where $I(jump\ at\ j)$ is the indicator function, equaling to 1 when jth observation is an jump or 0 otherwise, and the first (second) summation in (4) is the sample counterpart for continuous (jump) variance. Applying intraday prices and detected jumps to (4), we decompose the realized volatility into the continuous part and the jump part.

3.3 Jump Detection

We apply the nonparametric jump statistic developed by Lee and Mykland (2008) to identify intraday jumps in crude oil futures market. This methodology has the advantage to detect both occurrence and timing of jumps, and outperforms the jump statistic proposed by Brandorf-Nielsen and Shephard's (2006) in terms of the probability to successfully detect the actual jumps.

To fix ideas, consider a time series of 5-minute interval crude oil futures price denoted by $F(t_i)$. Lee and Mykland propose a statistic $\mathcal{L}(i)$ to gauge whether $F(t_i)$ jumps at t_i:

(5) $$\mathcal{L}(i) = \frac{\ln(F(t_i)) - \ln(F(t_{i-1}))}{\sigma(t_i)}$$

where $\sigma(t_i)$ is the realized *bi-power variation* (BV) (Brandorff-Nielsen and Shephard (2004)) estimated using the past K observations of $F(t_i)$:

(6) $$\sigma(t_i)^2 = BV_{t_i} = \frac{1}{K-2} \sum_{j=i-K+2}^{i-1} \left| \ln\left(F(t_j)\right) - \ln\left(F(t_{j-1})\right) \right| \left| \ln\left(F(t_{j-1})\right) - \ln\left(F(t_{j-2})\right) \right|.$$

The optimal choice of K is determined by the sampling frequency. Following Lee and Mykland (2008), we set K = 270 for our 5-minute interval data. Noticing that $\mathcal{L}(i)$ exhibits quite different limiting behavior depending on the existence of jump, Lee and Mykland propose an adjusted test statistic $\mathcal{L}(i)^*$:

(7) $$\mathcal{L}(i)^* = \frac{|\mathcal{L}(i)| - C_n}{S_n}$$

where $C_n = \frac{\sqrt{2\log(N)}}{c} - \frac{\log(\pi) + \log(log(N))}{2c\sqrt{2\log(N)}}$, $S_n = \frac{1}{c\sqrt{2\log(N))}}$, $c = \frac{\sqrt{2}}{\sqrt{\pi}}$ and N is the number of observations. One rejects the null hypothesis of no jump when $\mathcal{L}(i)^*$ is greater than the critical value β^*, where $\beta^* = -\log(-log(1-\alpha))$ for a given confidence level α. For jump detection, we use (7), setting α = 0.1% in order to avoid spurious detection.

3.4 Jump Predictor Test (JPT)

Lee (2012) proposes an inference technique called JPT to solve econometric challenges of identifying jump predictors using discrete data. Lee (2012) shows that the pseudo-likelihood constructed in JPT with discretely detected jumps asymptotically converges to the true likelihood. Thus, one can apply JPT to draw inference on determinants of the latent stochastic jump density and statistically test the linkage between the news announcement (jump predictor per se) and occurrence of jumps.

Lee (2012) proposes a logistic specification for JPT:

(8) $$d\Lambda_\theta(t) = \frac{1}{1+\exp(-\theta_0 - \sum_{j=1}^{N} \theta_j X_j(t))}$$

where $d\Lambda_\theta(t) = I(jump\ at\ t)$ is the dependent variable in the logistic regression, representing the instantaneous jump intensity at time t, and $X_j(t)$, $j = 1, \ldots, N$, is an explanatory variable corresponding to j^{th} jump predictor. To illustrate, let $X_1(t)$ be associated with crude oil inventory announcement, which equals to 1 if t is at announcement time or 0 otherwise. This specification allows one to statistically test whether crude oil inventory announcement significantly causes a price jump at announcement. The corresponding coefficient θ_1 has an economic interpretation: the crude oil inventory announcement changes the odds of jump arrival at announcement by a factor of $\exp(\theta_1)$. Hence, a positive (negative) θ_1 increase (decrease) the odds of jump arrival.

3.5 Estimation of Risk Neutral Model-Free Jump Variance (RNJV)

We examine the change of RNJV between Tuesday and Wednesday to investigate whether the option market can "predict" jumps in crude oil futures market induced by crude oil inventory announcement. Du and Kapadia (2011) find that the *risk-neutral* model-free implied holding period variance (*V*) is an accurate measure of quadratic variation of underlying return, while the *risk-neutral* model-free integrated variance (*IV* hereafter) is a downward biased estimator of quadratic variation when underlying process contains jumps. The difference between the two, i.e. *V* - *IV*, represents the variance component contributed by jumps.

Let $V(t,T)$ be the *risk-neutral* model-free holding period variance at time t for period from time t to T, and $IV(t,T)$ be the *risk-neutral* model-free integrated variance at time t for the same period. According to Bakshi, Kapadian and Madan (2003) and Carr and Wu (2009), $V(t,T)$ and $IV(t,T)$ can be estimated from set of European options:

(9)
$$V(t,T) = e^{r(T-t)}\left[\int_{S(t)}^{\infty} \frac{2\left(1-\ln\left(\frac{K}{S(t)}\right)\right)}{K^2} C(S(t);K,T)dK + \int_{-\infty}^{S(t)} \frac{2\left(1+\ln\left(\frac{S(t)}{K}\right)\right)}{K^2} P(S(t);K,T)dK\right] - \mu(t,T)^2$$

(10) $$IV(t,T) = e^{r(T-t)}\left[\int_{S(t)}^{\infty} \frac{2}{K^2} C(S(t);K,T)dK + \int_{-\infty}^{S(t)} \frac{2}{K^2} P(S(t);K,T)dK\right]$$

where $C(S(t);K,T)$ and $P(S(t);K,T)$ represent the call and put option price as time t with strike of K and maturity of T, respectively. The expression for $\mu(t,T)$ appears in Appendix A. In implementation, one can use trapezoidal approximation to compute the integrals. It follows that RNJV is estimated by:

$$RNJV(t,T) = V(t,T) - IV(t,T) \quad (11)$$

4 Data

4.1 Crude Oil Inventory Data

EIA reports weekly inventory of crude oil at 10:30AM on every Wednesday. We download the weekly inventory data from EIA's website (*http://www.eia.gov*). We also obtain the weekly survey of crude oil inventory from Bloomberg: On each Friday, the survey for next week's inventory level is drawn from a few highly reputed analysts, and we take the median as the best forecast by market. The inventory shock is then calculated as the difference between the realized inventory level and the best forecast. The corresponding time series of inventory level and shock are shown in Figure 1, spanning 565 weeks from July, 2003 through Mar, 2014. The basic statistics of weekly inventory shock are reported in Table 1. The inventory shock rejects the non-stationary hypothesis in Augment Dickey-Fuller test. The Ljung-Box statistics shows very weak persistence, implying that the weekly inventory shock is very difficult to forecast.

<Insert Figure 1>

<Insert Table 1>

4.2 Crude Oil Futures Data

We obtain from TickData the transaction records of crude oil futures, traded on New York Mercantile Exchange (NYMEX). The data contain transaction prices, volumes and timestamps for trades of crude oil futures with various maturities, covering 2,387 business days from July 1, 2003 to Dec 31, 2012. Following Gorton et al. (2012), we select the nearby futures contract, which is the nearest month contract that would not expire during the next month and is the most liquid in crude oil futures market. There are on average 60,670 nearby crude oil future contracts (32,390 transactions) traded per business day in our sample. To conduct empirical analysis, we sample the price every 5 minutes (calendar time sampling scheme; see Hansen and Lunde (2006)) to generate a 5-minute time interval price series. Figure 3 presents the time series of daily price sampled at 2:30PM and the realized variance (annualized and in standard deviation form), estimated using (1), for open outcry period (9:00AM -2:30PM)[6]. In addition, in section 5.3.2, we

[6] Prior to Jan 31, 2007, the open outcry trading hours were from 10:00AM to 2:30PM. Since Jan 31, 2007 the trading hours have been set at 9:00AM to 2:30PM.

use the 5-minute time interval data for the next 9 near futures with maturities up to one year for basis study.

<Insert Figure 3>

4.3 Options Data on Nearby Crude Oil Futures

We obtain from CME the daily price (settled at 3:30PM) of options on nearby crude oil futures contract for the period from July 1, 2003 to Dec 31, 2010. The options are American style, and we use the Barone-Adesi and Whaley (1987) pricing formula to infer the Black implied volatility. In order to get a good fit of implied volatility curve, which is used to generate set of OTM European options for the estimation of RNJV, we apply a few criteria to filter the option data: (1) we keep OTM options on nearby crude oil futures only; (2) we exclude options with days to expiration less than one week; (3) we exclude options violating standard no-arbitrage conditions; (4) we exclude options with open interest less than 100; (5) we exclude options having no transactions at the same day; (6) we exclude options with implied volatility smaller than 0.02 or larger than 500%; (7) we exclude options with price less than 2 cents. Besides, we skip days having less than two OTM calls or two OTM puts. Overall, the filtered sample contains 169,218 OTM options on nearby crude oil futures. The average maturity is 32 days and the average implied volatility is 0.46.

4.4 Data for Jump Predictors

We consider important market information as candidates of jump predictors for crude oil futures market. In particular, we include two energy-market specific reports (crude oil inventory report and natural gas inventory report) and several important macro-economic reports: Commitments of Futures Traders; Federal Open Market Committee Meeting (FOMC); Nonfarm Payroll Employment (NPE); Consumer Price Index (CPI); Producer Price Index (PPI); Industrial Production and Capacity Utilization (IPCU). Table 2 lists the announcement time and sources for each information variables used in this study. We collect the announcement time from official websites of sources.

<Insert Table 2>

5 Empirical Results

5.1 Jumps and Crude Oil Inventory Announcement

In this section, we investigate the linkage between jumps and crude oil inventory announcement in crude oil futures market. Using a calendar time sampling scheme, we generate 5-minute price series of nearby crude oil futures spanning from July 1, 2003 through Dec 31, 2011, and calculate the corresponding 5-minute returns; our sample has 234,360 return observations. By applying the jump statistics (7), we identify 1780 jumps occurring between 7:00AM and 4:00PM at 0.1% confidence level. Panel A in table 3 presents the summary statistics of identified jumps by weekday. The results show that the number of jumps on Wednesday is more than that on any other weekdays by almost 80%: 560 jumps occur on Wednesday, while 335, 316, 292 and 277 jumps occur on Thursday, Monday, Tuesday and Friday, respectively. Furthermore, panel B shows that a strikingly high proportion of jumps on Wednesday occur exactly at inventory announcement (26.9% at 10:35AM) and in the immediate subsequent period (29.5% between 10:35AM – 11:00AM). In contrast, the corresponding proportions at 10:35AM (between 10:35AM – 11:00AM) on other weekdays are 2.8% (8.5%) on Monday, 3.4% (13%) on Tuesday, 9.2% (20.3%) on Thursday and 1.1% (9%) on Friday, respectively.

<Insert Table 3>

The preliminary result implies that the crude oil inventory announcement may trigger jumps on Wednesday. For a formal statistical test of jump intensity, we adopt JPT which takes a logistic regression specification:

(12) $$d\Lambda_\theta(t) = \frac{1}{1+\exp(-\theta_0-\sum_{j=1}^{13}\theta_j X_j(t))}$$

where $d\Lambda_\theta(t)$ is a binary dependent variable indicating whether a jump occurs at time t (1) or not (0), and $X_j(t)$ is an indicator function associated with the j^{th} candidate of jump predictor. Specifically, we include 13 candidates of jump predictor to examine the characteristic of jumps in crude oil futures market:

$X_1(t)$ (OIL_AT) = I(t is at 10:35AM on Wednesday) is the indicator for jump occurring at crude oil inventory announcement.

$X_2(t)$ (OIL_AFT) = I(t is between 10:35AM and 11:00AM on Wednesday) is the indicator for jump occurring in the immediate subsequent period after crude oil inventory announcement.

$X_3(t)$ (OIL_BFE) = I(t is between 10:00AM and 10:30AM on Wednesday) is the indicator for jump occurring in the immediate preceding period prior to crude oil inventory announcement.

$X_4(t)$ (NG_AT) = I(t is at 10:35AM on Thursday) is the indicator for jump occurring at natural gas inventory announcement.

$X_5(t)$ (NG_AFT) = I(t is between 10:35AM and 11:00AM on Thursday) is the indicator for jump occurring in the immediate subsequent period after natural gas inventory announcement

$X_6(t)$ (CFT_AFT) = I(t is between 3:35PM – 4:00PM on Friday) is the indicator for jump occurring in the immediate subsequent period after the report of Commitment of Futures Trader.

$X_7(t)$ (FOMC_AFT) = I(t is between 2:20PM and 2:45PM on FOMC meeting day) is the indicator for jump occurring in the immediate subsequent period after the report of Federal Open Market Committee Meeting.

$X_8(t)$ (NONFARM_AFT) = I(t is between 8:35AM and 9:00AM on NPE release day) is the indicator for jump occurring in the immediate subsequent period after release of Nonfarm Payroll Employment.

$X_9(t)$ (CPI_AFT) = I(t is between 8:35AM and 9:00AM on CPI release day) is the indicator for jump occurring in the immediate subsequent period after release of Consumer Price Index.

$X_{10}(t)$ (PPI_AFT) = I(t is between 8:35AM and 9:00AM on PPI release day) is the indicator for jump occurring in the immediate subsequent period after release of Producer Price Index.

$X_{11}(t)$ (IPCU_AFT) = I(t is between 9:20AM and 9:45AM on IPCU release day) is the indicator for jump occurring in the immediate subsequent period after release of Industrial Production and Capacity Utilization.

$X_{12}(t)$ (PREMKT) = I(t is prior to 9:00AM) is the indicator for jump occurring in pre-market.

$X_{13}(t)$ (MORNING_HOUR) = I(t is between 9:00AM and 11:00AM) is the indicator for jump occurring in morning hour between 9:00AM and 11:00AM.

Table 4 reports the estimation result of the JPT. The sign and magnitude of estimated coefficients are of the most economic interest. Specifically, the exponential of the coefficient can be interpreted as a factor by which the odds of jump increases or decreases. We have several interesting findings:

First, the coefficients of *OIL_AT* (3.7432) and *OIL_AFT* (1.8841) are positive and statistically significant, implying that crude oil inventory announcement increase the odds of jumps at announcement by a factor of 42.23, and in the immediate subsequent period by a factor of 6.58. Hence, we *find empirical support for the hypotheses H1a and H1b1*, and verify that crude oil inventory announcement significantly increases the likelihood of jumps in crude oil futures market. In contrast, *OIL_BFE* is not statistically significant implying that before the inventory announcement at Wednesday 10:30am, the market is relatively quiet.

Second, the JPT results show that several other announcements, including the natural gas inventory announcement, FOMC meeting report, Nonfarm Payroll Employment report, and IPCU report, also significantly increase the likelihood of jumps. For example, the coefficient of Nonfarm Payroll Employment report (*NONFARM_AFT*) is 3.4141, implying that the report increases the odds of jump arrival in the subsequent period by a factor of 30.39. Among all candidates of jump predictors, assessed by the magnitude of coefficients, the crude oil inventory announcement and the Nonfarm Payroll Employment report are the two biggest influencers on crude oil futures market, followed by IPCU report and natural gas inventory announcement.

Interestingly, FOMC meeting report, which is considered one of the most important reports in equity and fixed income market, has relative smaller influence on crude oil futures market. Our findings provide evidence for a potential channel for the co-movement of volatilities between crude oil market and other markets.

Third, the coefficient of *PREMKT* is negative and significant, indicating that jumps are less likely to occur in pre-market trade. On the other hand, the coefficient of *MORNING_HOUR* is positive and significant, which is consistent with the stylized fact on the trading behavior in financial market: the morning hours tend to be volatile, resulting in more jumps.

Lastly, we find little evidence that CPI report, PPI reports and Commitment of Futures Report trigger jumps in crude oil futures market.

<Insert Table 4>

In summary, consistently with EMH, the JPT results show that the inventory announcement increases the odds of jump arrivals at announcement and in the immediate subsequent periods by a factor of 42.2 and 6.58, respectively, and the crude oil market is relative quiet before the inventory announcement. Furthermore, other announcements such as Natural Gas Inventory Report and Non-farmer Payroll Report also significantly increase the jump intensity, suggesting a potential channel for the co-evolution of volatilities between crude oil market and other financial markets.

5.2 Intraday Volatilities, Trading Activities and Crude Oil Inventory Announcement

In this section, we investigate the extent to which the crude oil inventory announcement affects intraday volatilities and trading activities on announcement days. Specifically, we partition each day-session (8:00AM to 2:30PM) into 13 consecutive intraday periods, denoted as P(k); k = 1, 2,…, 13, spanning 30 minutes each. Using 5-minute interval data spanning from July 1, 2003 through Dec 31, 2011, we compute the realized variance and number of trades (as a proxy for trading activities) for each intraday period.

To filter out influence due to factors other than the announcement, such as weekday effect, trading hour effect and expiration shrinkage effect, we run following two regressions in the first stage:

(13) $$Dep_i = \sum_{k=1}^{5} \alpha_k DummyWeekday_{i,k} + \theta \cdot t_i + \omega_i$$

(14) $$\omega_i = \sum_{k=1}^{13} \beta_k DummyHour_{i,k} + \upsilon_i$$

where Dep_i is annualized intraday volatility (number of trades) for an intraday period. $DummyWeekday_{i,1}$ = 1 when measure is on Monday, and 0 otherwise; $DummyWeekday_{i,2}$ = 1 when measure is on Tuesday, and 0 otherwise… ; $DummyWeekday_{i,5}$ = 1 when measure is on Friday, and 0 otherwise. t_i represents time to expiration in year. ω_i is the residual of (13), and acts as dependent variable in (14).$DummyHour_{i,k}$ = 1 when ω_i is for intraday period P(k), and 0 otherwise. v_i is the residual of (14), representing intraday volatility (number of trades) that has been corrected for weekday, trading hour and expiration shrinkage effects.

Table 5, panel A-B reports the regression result of (13). The coefficient of time to expiration, θ, is positive (negative) in panel A (B), supporting the stylized fact that when delivery month approaches, futures converges to spot and become less volatile and more liquid. The coefficients α_1-α_5 in panel A (B) represent the intraday volatility (number of trades), averaged by weekday and adjusted with expiration shrinkage effect. The results show that volatility (number of trades) in crude oil market tends to be low on Monday, and peaks on Wednesday. The top (bottom) panel in Figure 2 plots the coefficients (β_s)[7] in (14), representing the average intraday volatility (number of trades) during corresponding intraday period. The figure demonstrates a clear pattern: they tend to be low during pre-market, peak at 10:30AM, and peaks again at the end of day-session.

<Insert Table 5>

<Insert Figure 2>

In the second stage, we run regression of $v_i$on dummy variables to examine how the crude oil inventory announcement influence intraday volatilities and trading activities on announcement days. In the same regression, we also investigate such effects due to other major market reports, including Nonfarm Payroll Report, Natural Gas Inventory Report and IPCU Report, on their release days.

(15) $v_i = \alpha + \sum_{k=1}^{13} \gamma_k D^{oil}{}_{i,k} + \sum_{k=1}^{13} \delta_k D^{nonfarm}{}_{i,k} + \sum_{k=1}^{13} \theta_k D^{gas}{}_{i,k} + \sum_{k=1}^{13} \phi_k D^{ipcu}{}_{i,k} + \varepsilon_i$

where

v_i is the adjusted intraday volatility (number of trades) for an intraday period, obtained from (14)

$D_{i,k}^{oil}$ = 1 when v_i is for period P(k) on Wednesday (the day of crude oil inventory announcement), and 0 otherwise.

$D_{i,k}^{nonfarm}$ = 1 when v_i is for period P(k) on day of Nonfarm Employment Payroll Report, and 0 otherwise.

$D_{i,k}^{gas}$ = 1 when v_i is for period P(k)_on Thursday (the day of Natural Gas Inventory Report, and 0 otherwise.

$D_{i,k}^{ipcu}$ = 1 when v_i is for period P(k) on day of IPCU Report, and 0 otherwise.

[7] When making plot, we normalize the coefficients by adding back the sample average intraday volatility (number of trade).

We estimate (15) by OLS with Newey-West standard errors to correct for the autocorrelation and heteroscedasticity in errors. Table 6, Panel A-B presents the estimate result with Newey-West t-stats reported in parenthesis. Column 1 in both panels denotes the consecutive intraday periods between 8:00AM and 14:30PM, spanning 30 minutes each.

Column 2 in Panel A (B) reports the effects on intraday volatilities (number of trades) caused by crude oil inventory announcement. The results show that the announcement significantly increase the annualized intraday volatility (number of trades) in the immediate subsequent period after announcement, 10:30AM to 11:00AM on Wednesday, by 15.59% (2104), which *support the hypothesis H1b2 and H1b3*. Further, the triggered chaos seems to quickly cool off as the coefficients for succeeding periods become statistically insignificant. Interestingly, the coefficients for periods prior to the announcement are negative and highly significant, indicating that the crude oil futures market tends to be quiet when waiting for the crude oil inventory announcement.

Column 3 in Panel A (B) reports the effects caused by Nonfarm Payroll Report. There are some interesting findings: First, the Report significantly increase the annualized intraday volatility (number of trades) in the immediate subsequent period after the release, 8:30AM to 9:00AM on release day, by 11.02% (1265), indicating that the king of news in stock market also substantially affect the crude oil market; Second, for the period prior to announcement, 8:00AM to 8:30AM on release day, the increase in number of trades is both statistically and economically significant (Newy-West t-stat is 11.89 and coefficient is 1283), indicating that trading in crude oil market is exceptional active before the release of Nonfarm Payroll Report. However, we don't observe a significant increase in intraday volatility during the same period.

Column 4 & 5 in Panel A (B) report the effects caused by Natural Gas Inventory Report and IPCU Report. All coefficients corresponding to the immediate subsequent period after the release are statistically insignificant, implying that these two Reports do not impose substantial impact on intraday volatilities and trading activities in crude oil market.

<Insert Table 6>

In summary, consistently with EMH and our previous findings from JPT, the inventory announcement increases the intraday volatility and number of trades in the subsequent period after the announcement by 15.59% (annualized) and 2014 respectively, and the crude oil market appears less volatile before the announcement. In addition, the Non-farmer Payroll Report also significantly increases the intraday volatility (number of trades), but no such effects can be found for Natural Gas Inventory Report and IPCU Report. Another interesting finding is that the crude oil market is exceptional busy prior to the release of Non-farmer Payroll Report.

5.3 Efficient Market Hypothesis and Crude Oil Inventory Announcement

In this section, we examine how the shock of crude oil inventory influences the return and the basis of crude oil futures, as a test of Efficient Market Hypothesis in crude oil market.

5.3.1 On return of crude oil futures

Under null hypothesis H1c1 and H1d1, the crude oil inventory announcement should have no power to explain the return of crude oil futures in periods that are either before or after the announcement. To test the null hypothesis, we estimate the multivariate regression model:

(16) $$r_{i,k} = \alpha + \beta \cdot invetnoryShock_i + \gamma_0 \cdot basis_i + \gamma_1 \cdot shortRate_i + \gamma_2 \cdot yieldSprd_i + \gamma_3 \cdot laggedReturn_i + \sum_{j=1}^{N} \theta_j \cdot laggedVolatility_{i,j} + \epsilon_i$$

The dependent variable $r_{i,k}$ is the intraday period return on Wednesday of Week i, estimated by the difference between the logarithm of the closing and opening prices of the interval. We test four intraday periods: (1) overnight period (3:00PM on Tuesday to 10:00AM on Wednesday); (2) immediate preceding period before announcement (10:00AM to 10:30AM on Wednesday); (3) immediate subsequent period after announcement (10:35AM to 11:00AM on Wednesday); (4) remaining period (11:00AM to 3:00PM on Wednesday). The independent variable $invetnoryShock_i$ is the inventory shock on Wednesday of Week i, defined as the difference between the realized inventory and the best forecast by market. . To be consistent with the literature of futures (Hong and Yogo (2010)) and the literature of high frequency intraday return (Heston and Korajczy (2010)), we control variables that may have predictability on intraday return of futures: (1) $basis_i$, defined as the difference between futures price and spot price on Tuesday of Week i; we obtain the spot price of crude oil from the website of EIA; (2) $shortRate_i$, the U.S. one month Treasury Bill rate on Tuesday of Week i; (3) $yieldSprd_i$, the difference between Moody's Aaa corporate bond yield and U.S. one month Treasury Bill rate on Tuesday of Week i; we obtain the short rate and yield spread from the website of Federal Reserve Bank of St.Louis; (4) $laggedReturn_i$ and $laggedVolatility_{i,j}$, which denote the lagged intraday return and volatility (annualized). Table 7 presents their definitions under different intraday periods being considered.

<Insert Table 7>

We run the regression by OLS with Newey-West standard errors to correct for the autocorrelation and heteroscedasticity in errors. Our dataset contains 5-minutes interval price data of nearby crude oil futures spanning July 1, 2003 to Dec 31, 2011. We report the coefficients and the Newey-West t-statistics (in parenthesis) in Table 8, panels A-D.

<Insert Table 8>

The variable of primary interest is the inventory shock. Regressions 1, 4, 7 and 10 are univariate models, containing one explanatory variable (inventory shock) only. Regressions 2, 5, 8 and 11 examine the effect of control variables that may have power to explain intraday futures return. Regressions 3, 6, 9 and 12 investigate the influence of inventory shock in the presence of control variables.

Panel A presents the result for the immediate subsequent period after announcement (10:35AM to 11:00AM on Wednesday). None of the coefficient of inventory shock in both regression 1 and 3 is statistically significant. Besides, the adjusted R^2 in regression 1 is quite small (0.1%). In Panel B, similar results are also found for the remaining period (11:00AM to 3:00 PM on Wednesday): the shock has no power to explain the futures return in this period, and the gains in adjusted R^2 due to shock are almost zero. These results show that, on average, one cannot make profit by trading the inventory news in the immediate subsequent period and the remaining period after announcement. In other word, inventory shock has been fully impounded in a price at announcement. Therefore, we *fail to reject the hypothesis H1c1*.

Turning to Panel C, we examine the explanatory power of inventory shock to the return in the immediate preceding period before announcement (10:00AM to 10:30AM on Wednesday). In regression 7, the coefficient of inventory shock is negative (-0.004) and highly significant at the 0.1% level, and the adjusted R^2 equals to 6.3%. Notice that introducing the control variables in regression 9 has little influence on the effect of inventory shock: the coefficient of inventory shock rarely changes (-0.0039) and has the same significance level (0.1%). The findings from Panel C suggest that the intraday return in the immediate preceding period before announcement is negatively correlated to the inventory shocks, implying that the price of nearby crude oil futures tends to move up (down) before a negative (positive) inventory shock announcement. This is a sign of information leakage. Consequently, we *reject the hypothesis H1d1* with empirical findings that the information leakage occurs in the immediate preceding period before crude oil inventory announcement.

Panel D investigates whether information leakage happens overnight (3:00PM on Tuesday to 10:00AM on Wednesday). The coefficient of inventory shock in both regression 10 and 12 is negative (-0.0042) and statistically significant at the 1% level. Thus, the information leakage may happen overnight.

To evaluate the extent of information leakage, we may compare the significance of coefficient of inventory shock and the adjusted R^2 between regression 7 and regression 10. Clearly, regression 7 has a more statistically significant coefficient (at the 0.1% level vs at the 1% level) and a higher R^2 (0.063 vs 0.013). We conclude that the information leakage is more remarkable in the immediate preceding period before announcement.

In summary, we find that consistently with the EMH, inventory shock does not predict intraday crude oil futures returns after announcement. However, we find evidence for information leakage because the inventory shock predicts intraday and over-night returns before the announcement.

5.3.2 On basis of crude oil futures

As a further examination of EMH, we test the null hypothesis H1c2 and H1d2, under which the inventory shock should have no power to explain basis change in period either before or after the announcement. To this end, we use the nearby contract as our proxy of spot, denoted as M1, and compute basis for the next 9 near futures with maturity up to one year. These longer maturity futures are denoted as M2, M3…, M10. We run uni-variate regression of basis change, realized in different periods, on inventory shock. Because a change in yield curve also has influence on basis change, to eliminate such influence, we consider three short term periods: (1) prior to the announcement (9:00AM to 10:25AM); (2) spanning the announcement (10:25AM to 10:35AM); (3) after the announcement (10:35AM to 11:00AM), and assume that changes in yield curve during these short periods are negligible.

$$BasisChg_{i,k,m} = \alpha + \beta \cdot inventoryShock_i + \varepsilon_i \tag{17}$$

The dependent variable $BasicChg_{i,k,m}$ is basis change of futures m in period k on Wednesday of week i. The sign, magnitude and statistical significance of coefficient of inventory shock are of major interest. Our dataset contains 5-minutes interval price data of nearby crude oil futures as well as the next 9 near futures, spanning July 1, 2003 to Dec 31, 2011. We estimate (17) by OLS with Newey-West standard errors to correct for the autocorrelation and heteroscedasticity in errors. Table 9, panel A-C reports the estimate results with Newey-West t-statistics reported in parenthesis.

Panel A presents the result for the period spanning the announcement (10:25AM to 10:35AM on Wednesday). The results show that the coefficients of inventory shock for all considered futures (M2 to M10) are positive and significant statistically and economically. For instance, the futures M10 experiences a basis change of \$0.6861 per 10 million barrels inventory shock during this period. The findings are consistent with existing theories of commodities futures that a higher (lower) inventory increase (decrease) the basis.

Panel B presents the result for the period before the announcement (9:00AM to 10:25AM on Wednesday). The coefficient of inventory shock is positive and highly significant for futures M2, and marginal significant for futures M3, M5 and M6. This result confirms our previous finding that information leakage may occur before the announcement. Therefore we *reject the hypothesis H1c2.*

Panel C presents the result for the period after the announcement (10:35AM to 11:00AM on Wednesday). Surprisingly, futures M3, M4, M5, M6 and M9 record highly significant but negative coefficients of inventory shock. This finding implies that some longer maturity futures, unlike the nearby futures whose price immediately impound the inventory shock at 10:35AM, demonstrate a gradual response to the shock. In consequence, the basis changes of some longer maturity futures at 10:35AM due to inventory shock appear to be “overshooting”, and then revert back to the “right” level in succeeding periods. Consider a simple numerical example for illustration: Assuming there is a positive inventory shock in the announcement. At 10:35AM, the spot immediately impounds the positive shock and its price plummets to \$98, while the considered longer maturity futures price remains unchanged at \$104. Assuming the longer maturity futures “spends” 25 minutes to impound the shock, and its price drops to \$103 at 11:00AM. Thus, in the presence of the positive inventory shock, the basis of the longer maturity futures decreases from \$6 at 10:35AM to \$5 at 11:00AM. The basis change result *rejects the hypothesis H1d2*, providing evidence that the crude oil market as a whole is not an efficient market in the presence of the inventory announcement.

In summary, we confirm the positive correlation between basis chage and inventory shock as postulated by existing theories of commodities futures. We also find evidence to support information leakage. However, differently from our finding from previous return study, we document evidence that the inventory shock can explain the basis change in the period after the announcement, casting doubt on crude oil market’s efficiency as a whole.

5.4 Volatility-Volume relation and Crude Oil Inventory Announcement

In this section, we study whether the crude oil inventory announcement have influence on the contemporaneous volatility-volume relation for nearby crude oil futures.

We first compute the daily (from 9:00AM to 3:00PM) realized volatility by (1), using the 5-minute interval price data of nearby crude oil futures, and then decompose it into two components by applying the technique described in subsection 3.2. Notice that the detected jumps in the 5-mintute interval price data are used to disentangle the jump component of realized volatility. Figure 4 illustrates the decomposition results. The top (bottom) panel plots the time series of annualized continuous (jump) volatility during the sample period.

<Insert Fig.4>

To exclude the trending and expiration shrinkage effect in raw trading volumes[8], we run the non-linear model:

$$Volume_t = \alpha_0 + \alpha_1 \cdot t + \alpha_2 \cdot t^2 + \alpha_3 \cdot dte_t + \alpha_4 \cdot dte_t^2 + v_t \quad (18)$$

where $Volume_t$ is the raw trading volume scaled by 10,000 at day *t*, dte_t represents the days to expiration. The residual v_t is the adjusted trading volumes.

[8] At each business day, we count volume of all trades occurring between 9:00AM to 3:00PM to obtain the raw trading volumes.

Following Giot et al. (2010) and Chevallier and Sevi (2013), we estimate the regressions represented by (19) and (20) to test the contemporaneous relation between realized volatility and trading volumes.

(19) $$CRV_t = \beta_0 + \sum_{k=1}^{12} \beta_k \cdot CRV_{t-k} + \theta \cdot v_t + \varepsilon_t$$

(20) $$JRV_t = \beta_0 + \sum_{k=1}^{12} \beta_k \cdot JRV_{t-k} + \theta \cdot v_t + \varepsilon_t$$

where CRV_t is the continuous component of realized variance, $JRV_t$is the jump component of realized variance, twelve auto-regressive terms are included in both equations to account for the dynamic of conditional variance, v_t is the adjusted trading volumes. The regressions are estimated by OLS with Newey-West errors to correct for autocorrelation and heteroscedasticity in ε_t.

We partition our sample into 4 sub-periods: July 1, 2003 through Dec 31, 2005; Jan 1, 2006 through Dec 31, 2007; Jan 1, 2008 through Dec 31, 2009; Jan 1, 2010 through Dec 31, 2011. For whole period and each sub-period, we run separate regressions by day-of-the-week, and also run regression for all days as a whole. We report the regression results in table 10. The sign and statistical significance of the slope coefficient of trading volumes are of primary interest.

<Insert Table 10>

Panel A presents the results for continuous volatility. The whole period (top panel) results show that the slope coefficients of trading volumes in all test are positive and statistically significant at 1% level, which are in line with Giot et al. (2010) and Chevallier and Sevi (2013), who find positive contemporaneous relation between continuous volatility and trading volumes. Therefore, our empirical finding *supports the hypothesis H2a*. Notice that the coefficient estimated for Wednesday is relatively smaller and less significant (but still at 1% level) than those for other weekdays. This is a sign that the crude oil inventory may have some influence on the volatility-volume relation, while its influence on the continuous component of volatility is not obvious. The results from sub-periods are similar: all estimated slope coefficients of trading volume are positive; and most of them are statistically significant at 1% level.

Table B presents the results for jump volatility. There are a few interesting findings: (1) The whole period results show that, on average, the coefficient of trading volume is positive and statistically significant, which agrees with Chevallier and Sevi's (2013) finding in crude oil futures market. However, a further examination at day-of-the-week level shows that the coefficient estimated for Wednesday is insignificant (the t-statistic is merely 0.165). Since a large proportion of jumps on Wednesday are induced by crude oil inventory announcement, it follows that the announcement has sizable influence on the contemporaneous relation between jump volatility and trading volumes. (2) This influence becomes even more significant in sub-period between Jan 1, 2008 and Dec 31, 2009 (recent recession time): the estimated coefficient for Wednesday in this period is negative and statistically significant at 5% level. (3) Such influence is not obvious on other weekdays. Our finding *does not support the hypothesis H2b*, and provides empirical evidence that the MDH may not hold for jump component of volatility in crude oil futures market.

We propose an explanation to our finding: Market participant's reaction to jump is different for source of jump. When jump is triggered by public news, such as crude oil inventory announcement, market participants tend to trade *less* because they agree that the market is right in interpreting the public news, and the positive volatility-volume relation is therefore *broken up*. On the other hand, when jump occurs and is not related to any public known news, market participants tend to have conflict opinions on the prevailing price, which leads to *more* trades and *reinforce* the positive relation between volatility and volumes.

To verify our explanation, we examine the relation between the absolute 5-minute log return of the nearby futures at 10:35AM and the volume (or number of trades[9]) in the subsequent period (10:35AM to 11:00AM) on Wednesday (a jump occurring at 10:35AM is caused by public news, the crude oil inventory announcement) versus on other weekdays[10] (a jump occurring at 10:35AM is not related to any public known news). Specifically, we run following regressions

(21) $$absRet_t^J = \alpha + \beta \cdot V_t + \sum_{k=1}^{6} \gamma_k \cdot absRet_{t-k} + \varepsilon_t$$

(22) $$absRet_t^J = \alpha + \beta \cdot N_t + \sum_{k=1}^{6} \gamma_k \cdot absRet_{t-k} + \varepsilon_t$$

(23) $$absRet_t^C = \alpha + \beta \cdot V_t + \sum_{k=1}^{6} \gamma_k \cdot absRet_{t-k} + \varepsilon_t$$

(24) $$absRet_t^C = \alpha + \beta \cdot N_t + \sum_{k=1}^{6} \gamma_k \cdot absRet_{t-k} + \varepsilon_t$$

where $absRet_t^J$ ($absRet_t^C$) is the absolute 5-minute log return observed at 10:35AM when the past 5 minutes price move is identified as a jump process (continuous process). V_t (N_t) is the trading volume (number of trades) in the subsequent period between 10:35AM to 11:00AM, corrected for trending and expiration shrinkage effects and scaled by 10,000. We include six lagged absolute 5-minute log returns to account for persistency. We run all regression for Wednesday and for other weekdays, respectively. The estimate is by OLS with Newey-West errors to correct for autocorrelation and heteroscedasticity.

Table 11 presents the estimate results. The sign, magnitude and statistical significance of slope coefficients of volume and number of trades are of primary interest. The results support our explanation: (1) When price move at 10:35AM is a jump process, the estimated coefficient of volume (number of trades) is -0.0002 (-0.0008) on Wednesday. In contrast, the same coefficient

[9] In addition to trading volume, number of trades is an alternative measure on trading activities.
[10] Since the Natural Gas Report is released on Thursday, 10:00AM, we only consider Monday, Tuesday and Friday as other weekdays to ensure that the jumps occurs on 10:35AM on other weekdays is not caused by any public known news.

is 0.0009 (0.0017) and statistically significant on other weekdays. This finding indicates that the positive volatility-volume relation is broken up in the presence of jump, which is induced by public known news, such as the inventory announcement. (2) When price move at 10:35AM is a continuous process, the coefficients of volume and number of trades on both Wednesday and other weekdays are positive and significant, which is consistent with previous literature that the positive volatility-volume relation holds in continuous process. (3) On other weekdays, coefficients under jump process are substantially larger and more significant than under continuous process, indicating that the positive volatility-volume relation is reinforced in the presence of jump, which is not triggered by public known news.

<Insert Table 11>

In summary, as suggested by the MDH, we find a positive relation between the continuous part of volatility and volume, which is consistent with previous literature. However, we do not necessarily document such a positive relation in the case of the jump part of volatility on Wednesdays, a finding inconsistent with the MDH. Our explanation for the negative contemporaneous relation between jump component of volatility and trading volumes in the presence of crude oil inventory announcement is as follows: some market participants may trade *less* in the presence of jump triggered by public news because they agree that the market is right in interpreting the public news.

5.5 Options and Jumps induced by Crude Oil Inventory Announcement

We apply (9), (10) and (11) to estimate the risk neutral model free jump variance (RNJV) implied by option market. We follow Duan and Wei (2010) to compute the integrals in (9) and (10) by a trapezoidal approximation. The key step in estimation is to get the set of OTM European options. To this end, we use the SVI parameterization[11] to fit the implied volatility curve. For strikes below (above) the lowest (highest) available strike in the market, we use the implied volatility at the lowest (highest) available strike. After obtaining the fitted volatility curve, we follow Carr and Wu's (2009) procedure to generate a fine grid of 2,000 implied volatility points with a strike range of ± 8 standard deviations (use ATM implied volatility as proxy) from the current crude oil futures price. Using the fine grid of implied volatilities, we obtain the set of European OTM options and compute their prices by the Black-Sholes formula.

Table 12 reports the 5th percentile, the median, and the 95th percentile of the risk neutral jump variance (RNJV), holding period variance, skewness and kurtosis by year. All reported risk neural momentums are estimated for the synthetic 30-days maturity[12], using daily options on crude oil futures, spanning Jul 1, 2003 through Dec 31, 2010. The results show that

[11] The SVI parameterization is proposed by Jim Gatheral (2004). See Appendix B for technique details

[12] For each business day, we construct the risk neutral momentum for two maturities that are most close to 30-days, and then linearly interpolate the corresponding risk neutral momentum for the synthetic 30-days maturity. We use the same filter criteria described in section 3.3 to clean the option data for the two maturities.

the RNJV is time varying, positive on average, and becomes significantly larger during 2008 – 2010, implying that option markets expect more jumps would happen during recession time. Table 13 presents the correlations among risk neutral momentums. Interestingly, there is a strong correlation (-0.76) between the RNJV and the risk neutral skewness, while the correlation between the risk neutral holding period variance and skewness is rather weak (-0.13). This finding indicates that the RNJV indeed captures the jump variance component in the risk neutral holding period variance, because it is well established in the literature that jumps are manifested in the distribution of underlying return by affecting skewness.

<Insert Table 12>

<Insert Table 13>

In order to explore the predictability of option market on jumps in crude oil futures induced by scheduled crude oil inventory announcement, we use daily options on nearby crude oil futures to construct RNJV, and examine whether there is abnormal change of RNJV between Tuesday and the following Wednesday. Table 14 presents the sample mean and median of the RNJV, risk neutral holding period variance, skewness and kurtosis by day-of-the–week for the sample period. The results show that on average there is no abnormal change of RNJV between Tuesday and Wednesday, indicating that the closing option prices on Tuesday contain little information to "forecast" that more jumps would occur during the next day induced by scheduled crude oil inventory announcement. Hence, we *fail to find empirical support for the hypothesis H3*.

<Insert Table 14>

6 Conclusions

To understand how commodity market impounds inventory information, we investigate crude oil futures and options market, where high-frequency data are available and inventory news is announced periodically. Our findings can be summarized as follows: (1) Consistently with the EMH, the crude oil futures market does not exhibit many jumps before the announcement, and an inventory announcement increases the odds of jump arrival of nearby crude oil futures price at announcement (in the immediate subsequent periods of 10:35AM to 11:00AM Wednesday) by a factor of 42.23 (6.58) during our sample period. These findings suggest that it may take at least 30 minutes for market to digest inventory news. (2) Trading on the realized inventory shock does not produce any excess return, but there is strong evidence for inventory information leakage. (3) Because some traders may trade *less* in the presence of jumps triggered by announced public information, we find a negative relationship between trading volume and the jump part of volatility on the day of inventory news announcement. (4) We do not find any evidence that the options contain forward looking information of jumps induced by public information.

We employ the JPT to rigorously examine the linkage between jumps in crude oil futures market and crude oil inventory report, as well as other major market news. As recent commodity literature highlights the importance of inventory, we find that the crude oil inventory announcement is the king of news in crude oil futures market.

Our findings are relevant to risk managers and regulators. First, risk managers should consider predictable price jumps on the inventory announcement day in their risk models and procedures. Second, regulators such as EIA may want to prevent important macro-economic news from leaking before official announcement.

This paper may open a new avenue for future research. First, an empiricist may extend our analysis to other commodity markets where an inventory news announcement occurs periodically. Second, a financial theorist may use heterogeneity in beliefs, information asymmetry, and continuum of investors to devise a formal equilibrium model to explain the negative correlation between trading volume and the jump part of volatility after a public news announcement.

Appendix A: Estimation of Risk Neutral Skewness and Kurtosis

Let $S(t)$ be the time t price of the underlying, and let $V(t,\tau), W(t,\tau)$ and $X(t,\tau)$ be the time t price of τ-period quadratic, cubic and quartic contracts written on the underlying, respectively. According to Bakshi, Kapadia, and Madan (2003), the risk neutral skewness and kurtosis for τ-period return of underlying can be expressed as:

(25) $$Skewness(t,\tau) = \frac{e^{r\tau}\left(W(t,\tau) - 3\mu(t,\tau)V(t,\tau)\right) + 2\mu(t,\tau)^3}{[e^{r\tau}V(t,\tau) - \mu(t,\tau)^2]^{3/2}}$$

(26) $$Kurtosis(t,\tau) = \frac{e^{r\tau}X(t,\tau) - 4\mu(t,\tau)e^{r\tau}W(t,\tau) + 6\mu(t,\tau)^2 e^{r\tau}V(t,\tau) - 3\mu(t,\tau)^4}{[e^{r\tau}V(t,\tau) - \mu(t,\tau)^2]^2}$$

where

(27) $$\mu(t,\tau) = e^{r\tau} - 1 - \frac{e^{r\tau}}{2}V(t,\tau) - \frac{e^{r\tau}}{6}W(t,\tau) - \frac{e^{r\tau}}{24}X(t,\tau)$$

(284) $$V(t,\tau) = \int_{S(t)}^{\infty} \frac{2\left(1 - \ln\left(\frac{K}{S(t)}\right)\right)}{K^2} C(t,\tau,K)dK + \int_{0}^{S(t)} \frac{2\left(1 + \ln\left(\frac{K}{S(t)}\right)\right)}{K^2} P(t,\tau,K)dK$$

(29) $$W(t,\tau) = \int_{S(t)}^{\infty} \frac{6\ln\left(\frac{K}{S(t)}\right) - 3[\ln\left(\frac{K}{S(t)}\right)]^2}{K^2} C(t,\tau,K)dK - \int_{0}^{S(t)} \frac{6\ln\left(\frac{S(t)}{K}\right) + 3[\ln\left(\frac{S(t)}{K}\right)]^2}{K^2} P(t,\tau,K)dK$$

(30)
$$X(t,\tau) = \int_{S(t)}^{\infty} \frac{12\left(\ln\left(\frac{K}{S(t)}\right)\right)^2 - 4\left(\ln\left(\frac{K}{S(t)}\right)\right)^3}{K^2} C(t,\tau,K)dK + \int_{0}^{S(t)} \frac{12\left(\ln\left(\frac{S(t)}{K}\right)\right)^2 + 4\left(\ln\left(\frac{S(t)}{K}\right)\right)^3}{K^2} P(t,\tau,K)dK$$

where $C(t,\tau,K)$ and $P(t,\tau,K)$ are t time price of τ-period European Call and Put options written on the underlying, respectively.

Appendix B: Stochastic Volatility Inspired (SVI) Parameterization

Gatheral (2004) introduces the stochastic volatility inspired (SVI) model to parameterize the implied variance:

(27) $$v(x,T) = a + b(\rho(x - m) + \sqrt{(x-m)^2 + \sigma^2}$$

where x is log-moneyness, defined as $\ln(\frac{K}{F(T)})$; K is the strike; F(T) is the forward price with maturity T; $v(x,T)$ is implied variance for maturity T and log-moneyness x; $a, b, \rho, m \ and \ \sigma$ are model parameters, which can be calibrated by minimizing the mean square errors between model volatility and market volatility.

Tables

Table 1. Basic statistics of weekly U.S. inventory shock of crude oil

Series	Mean	Std. Dev.	Median	Skewness	Kurtosis	Ljung-Box(10)	ADF pValue
Weekly Inventory Shock (Thousand Barrels)	805	3059	75	-0.1862	3.2137	19.8268	0.001

This table reports the summary statistics on weekly U.S. inventory shock of crude oil, defined as the difference between the realized inventory level and the best forecast by market. The level data is obtained from EIA's website , covering 565 weeks from July, 2003 to March, 2014. On each Friday, a survey for next week's inventory level is drawn from a few highly reputed analysts. We obtain the survey data from Bloomberg and take the median number as the best forecast by market.

Table 2. Description of Information Variables in Crude Oil Futures Market

Information Variable Names	Announcement Time	Frequency	Data Source
Crue Oil Inventory	10:30AM	Every Wednesday	Energy Information Administration
Natrual Gas Inventory	10:30AM	Every Thursday	Energy Information Administration
Commitments of Futures Traders	3:30PM	Every Friday	U.S. Commodity Futures Trading Commision
Federal Open Market Committee Meeting	14:15PM	Irregular (6 or 7 times per year)	Federal Reserve Board
Nonfam Payroll Employment	8:30AM	Irregular (once a month)	Bureau of Labor Statistics
Consumer Price Index	8:30AM	Irregular (once a month)	Bureau of Labor Statistics
Producer Price Index	8:30AM	Irregular (once a month)	Bureau of Labor Statistics
Industrial Production and Capacity Utilization	9:15AM	Irregular (once a month)	Federal Reserve Board

This table presents the announcement time, announcement frequency and data source of each information variable used in jump predictive analysis in crude oil futures market. All informations are collected from official website of sources.

Table 3. Summary Statistics of Jumps in Crude Oil Futures Market

Panel A: summary of jumps					
	Mon	**Tue**	**Wed**	**Thu**	**Fri**
Nobs	45792	47628	47952	47196	45792
Jumps	316	292	560	335	277
Positive Jumps	133	127	271	138	126
Negative Jumps	183	165	289	197	151
P(Jumps)	0.69%	0.61%	1.17%	0.71%	0.60%
P(Jumps(+))	0.29%	0.27%	0.57%	0.29%	0.28%
P(Jumps(-))	0.40%	0.35%	0.60%	0.42%	0.33%

Panal B: number of jumps in intraday time period					
	Mon	**Tue**	**Wed**	**Thu**	**Fri**
7:00AM - 10:00AM	52	51	27	39	51
10:00AM - 10:30AM	81	122	79	75	109
10:35AM	9	10	151	31	3
10:35AM - 11:00AM	27	38	165	68	25
11:00AM - 4:00PM	147	122	166	160	140

This table reports the summary statistics of jumps in nearby crude oil futures by day-of-the-week. *Nobs* is the number of return observation. *Positive (Negative) Jumps* is the number of jumps spiking up (down). *P(jumps), P(jumps(+))* and *P(jumps(-))* are the unconditional probabilities of jumps, positive jumps and negative jumps, respectively. Panel B presents the number of jumps in different intraday trading time period. The jump detection technique described in section 3.3 is applied to detect jumps in the 5-minutes interval price data of nearby crude oil futures, spanning July 1, 2003 through Dec 31, 2011.

Table 4. Jump Predictor Test Results for Crude Oil Futures Market

	Coeff.	t_statistic	p_value
Intercept	-5.1453	-138.33	0.00 ***
OIL_AT(10:35am WED)	3.7432	34.26	0.00 ***
OIL_AFT(10:35am – 11:00am WED)	1.8841	20.49	0.00 ***
OIL_BFE (10:00am – 10:30am WED)	-0.1754	-0.8848	0.38
NG_AT (10:35am THU)	1.8338	9.58	0.00 ***
NG_AFT (10:35am – 11:00am THU)	0.9679	7.41	0.00 ***
CFT_AFT (3:35pm – 4:00pm FRI)	-92.4207	-0.0001	0.9999
FOMC_AFT (2:20pm – 2:45pm on FOMC day)	1.0973	2.86	0.004 ***
NONFARM_AFT (8:35am – 9:00am on NONFARM day)	3.4141	12.05	0.00 ***
CPI_AFT (8:35am – 9:00am on CPI day)	0.7938	-0.71	0.48
PPI_AFT (8:35am – 9:00am on PPI day)	-0.3934	-0.36	0.72
IPCU_AFT (9:20am – 9:45am on IPCU day)	2.1738	3.58	0.0003 ***
PREMKT (7:00am – 9:00am)	-1.7934	-12.35	0.00 ***
MORNING_HOUR (9:00am – 11:00am)	0.7392	12.89	0.00 ***

This table presents the estimation results of Jump Predictor Test (JPT) on jumps identified from the 5-minutes interval price data of nearby crude oil futures, spanning July 1, 2003 through Dec 31, 2011. The JPT has a logistic regression specification

$$d\Lambda_{\theta}(t) = \frac{1}{1 + \exp(-\theta_0 - \sum_{j=1}^{13} \theta_j X_j(t))}$$

where $d\Lambda_{\theta}(t)$ is a binary variable indicating whether a jump occurs at time t (1) or not (0). $X_j(t)$ is an indicator function associated with the j^{th} candidate of jump predictor, defined as

$X_1(t)$ (OIL_AT) = I(t is at 10:35AM on Wednesday) is the indicator for jump occurring at crude oil inventory announcement.

$X_2(t)$ (OIL_AFT) = I(t is between 10:35AM and 11:00AM on Wednesday) is the indicator for jump occurring in the immediate subsequent period after crude oil inventory announcement.

$X_3(t)$ (OIL_BFE) = I(t is between 10:00AM and 10:30AM on Wednesday) is the indicator for jump occurring in the immediate preceding period prior to crude oil inventory announcement.

$X_4(t)$ (NG_AT) = I(t is at 10:35AM on Thursday) is the indicator for jump occurring at natural gas inventory announcement.

$X_5(t)$ (NG_AFT) = I(t is between 10:35AM and 11:00AM on Thursday) is the indicator for jump occurring in the immediate subsequent period after natural gas inventory announcement

$X_6(t)$ (CFT_AFT) = I(t is between 3:35PM – 4:00PM on Friday) is the indicator for jump occurring in the immediate subsequent period after the report of Commitment of Futures Trader.

$X_7(t)$ (FOMC_AFT) = I(t is between 2:20PM and 2:45PM on FOMC meeting day) is the indicator for jump occurring in the immediate subsequent period after the report of Federal Open Market Committee Meeting.

$X_8(t)$ (NONFARM_AFT) = I(t is between 8:35AM and 9:00AM on NPE release day) is the indicator for jump occurring in the immediate subsequent period after release of Nonfarm Payroll Employment.

$X_9(t)$ (CPI_AFT) = I(t is between 8:35AM and 9:00AM on CPI release day) is the indicator for jump occurring in the immediate subsequent period after release of Consumer Price Index.

$X_{10}(t)$ (PPI_AFT) = I(t is between 8:35AM and 9:00AM on PPI release day) is the indicator for jump occurring in the immediate subsequent period after release of Producer Price Index.

$X_{11}(t)$ (IPCU_AFT) = I(t is between 9:20AM and 9:45AM on IPCU release day) is the indicator for jump occurring in the immediate subsequent period after release of Industrial Production and Capacity Utilization.

$X_{12}(t)$ (PREMKT) = I(t is prior to 9:00AM) is the indicator for jump occurring in pre-market.

$X_{13}(t)$ (MORNING_HOUR) = I(t is between 9:00AM and 11:00AM) is the indicator for jump occurring in morning hour between 9:00AM and 11:00AM.

Table 5. Weekday and Expiration Shrinkage Effects on Daily Volatilities and Trading Activities

Panel A: result for intraday volatilities					
MON	**TUE**	**WED**	**THUR**	**FRI**	**T2EXP**
0.2086	0.217	0.2357	0.2315	0.2254	0.1309

Panel B: result for intrayday number of trade					
MON	**TUE**	**WED**	**THUR**	**FRI**	**T2EXP**
10,032	10,370	10,552	10,503	10,402	-62,528

This table reports the weekday and expiration shrinkage effects on daily volatilities (Panel A) and trading activities (Panel B), estimated from the following model

$$Dep_i = \sum_{k=1}^{5} \alpha_k DummyWeekday_{i,k} + \theta \cdot t_i + \omega_i$$

where Dep_i is annualized volatility (Panel A) or number of trades (Panel B).for an intraday period. $DummyWeekday_{i,1}$ = 1 when measure is on Monday, and 0 otherwise; $DummyWeekday_{i,2}$ = 1 when measure is on Tuesday, and 0 otherwise; $DummyWeekday_{i,3}$ = 1 when measure is on Wednesday, and 0 otherwise; $DummyWeekday_{i,4}$ = 1 when measure is on Thursday, and 0 otherwise; $DummyWeekday_{i,5}$ = 1 when measure is on Friday, and 0 otherwise. t_i is time to expiration in year. Sample contains 5-minute interval data of nearby crude oil futures of crude oil, spanning July, 2003 through December, 2011. Estimation is by OLS.

Table 6. Major Market News on Intraday Volatilities and Trading Activities

Panel A: Results for Intraday Volatilities								
Intraday Periods	**Effect by crude oil inventory announcement**		**Effect by Nonfarm Payroll Report**		**Effect by Natural Gas Inventory Report**		**Effect by IPCU Report**	
P1 *(8:00AM - 8:30AM)*	γ_1	-0.0162 (-3.092 ***)	δ_1	0.0132 (1.2046)	θ_1	-0.0040 (-0.581)	ϕ_1	-0.009 (-0.085)
P2 *(8:30AM - 9:00AM)*	γ_2	-0.0271 (-4.645 ***)	δ_2	0.1102 (4.369 ***)	θ_2	-0.0058 (-0.890)	ϕ_2	0.0141 (1.021)
P3 *(9:00AM - 9:30AM)*	γ_3	-0.0459 (-7.360 ***)	δ_3	0.0342 (1.791 *)	θ_3	0.0027 (0.3217)	ϕ_3	0.0205 (1.315)
P4 *(9:30AM - 10:00AM)*	γ_4	-0.0385 (-5.4573)	δ_4	0.0202 (0.989)	θ_4	-0.0044 (-0.493)	ϕ_4	-0.0021 (-0.1315)
P5 *(10:00AM - 10:30AM)*	γ_5	-0.0428 (-6.496 ***)	δ_5	0.0366 (2.041 **)	θ_5	-0.005 (-0.656)	ϕ_5	0.0039 (0.275)
P6 *(10:30AM - 11:00AM)*	γ_6	0.1559 (12.254 ***)	δ_6	-0.0374 (-2.074 **)	θ_6	-0.0017 (-0.193)	ϕ_6	-0.0089 (-0.367)
P7 *(11:00AM - 11:30AM)*	γ_7	0.0257 (3.250 ***)	δ_7	0.0066 (0.396)	θ_7	0.0113 (1.251)	ϕ_7	-0.0030 (-0.163)
P8 *(11:30AM - 12:00PM)*	γ_8	0.007 (1.020)	δ_8	0.0061 (0.394)	θ_8	0.0083 (1.137)	ϕ_8	0.0042 (0.313)
P9 *(12:00PM - 12:30PM)*	γ_9	0.0015 (0.2287)	δ_9	0.0160 (1.078)	θ_9	-0.0002 (-0.033)	ϕ_9	0.026 (1.899 *)
P10 *(12:30PM - 13:00PM)*	γ_{10}	-0.0009 (-0.138)	δ_{10}	-0.0057 (-0.441)	θ_{10}	0.0078 (1.096)	ϕ_{10}	0.0167 (1.172)
P11 *(13:00PM - 13:30PM)*	γ_{11}	0.0028 (0.381)	δ_{11}	0.0181 (1.199)	θ_{11}	0.0062 (0.893)	ϕ_{11}	-0.0114 (0.8524)
P12 *(13:30PM - 14:00PM)*	γ_{12}	0.0023 (0.311)	δ_{12}	0.0089 (0.610)	θ_{12}	0.0079 (1.078)	ϕ_{12}	-0.0014 (0.097)
P13 *(14:00PM - 14:30PM)*	γ_{13}	0.0024 (0.246)	δ_{13}	0.0030 (0.1534)	θ_{13}	0.0019 (0.205)	ϕ_{13}	-0.0189 (-0.960)

Panel B: Results for Intraday Trading Activities (number of trades)

Intraday Periods		Effect by crude oil inventory announcement		Effect by Nonfarm Payroll Report		Effect by Natural Gas Inventory Report		Effect by IPCU Report
P1 *(8:00AM - 8:30AM)*	γ_1	-187.95 (-1.716 *)	δ_1	1283.02 (11.89 ***)	θ_1	-157.75 (-1.346)	ϕ_1	-139.01 (-1.394)
P2 *(8:30AM - 9:00AM)*	γ_2	-289.85 (-2.481 ***)	δ_2	1264.94 (8.38 ***)	θ_2	66.43 (0.474)	ϕ_2	-96.82 (-0.463)
P3 *(9:00AM - 9:30AM)*	γ_3	-650.16 (-4.536 ***)	δ_3	115.69 (0.792)	θ_3	138.43 (0.637)	ϕ_3	-317.33 (-1.085)
P4 *(9:30AM - 10:00AM)*	γ_4	-614.28 (-3.359 ***)	δ_4	-411.21 (-2.896 ***)	θ_4	37.62 (0.159)	ϕ_4	-557.05 (-1.757 *)
P5 *(10:00AM - 10:30AM)*	γ_5	-690.29 (-4.134 ***)	δ_5	-347.48 (-2.327 ***)	θ_5	-23.05 (-0.105)	ϕ_5	-587.56 (-2.296 ***)
P6 *(10:30AM - 11:00AM)*	γ_6	2104.51 (6.468 ***)	δ_6	-807.92 (-5.912 ***)	θ_6	-348.28 (-1.731 *)	ϕ_6	-1197.52 (4.050 ***)
P7 *(11:00AM - 11:30AM)*	γ_7	311.73 (1.498)	δ_7	-408.36 (-2.833 ***)	θ_7	98.53 (0.465)	ϕ_7	-696.67 (-2.466 ***)
P8 *(11:30AM - 12:00PM)*	γ_8	133.39 (0.734)	δ_8	32.86 (0.24)	θ_8	-91.29 (-0.546)	ϕ_8	-150.85 (-0.479)
P9 *(12:00PM - 12:30PM)*	γ_9	-36.93 (-0.239)	δ_9	342.57 (2.777 ***)	θ_9	-77.46 (-0.548)	ϕ_9	-173.87 (0.810)
P10 *(12:30PM - 13:00PM)*	γ_{10}	-60.74 (-0.436)	δ_{10}	480.31 (4.085 ***)	θ_{10}	-5.3 (-0.038)	ϕ_{10}	-262.05 (-1.42)
P11 *(13:00PM - 13:30PM)*	γ_{11}	-125.55 (-0.885)	δ_{11}	435.29 (3.630 ***)	θ_{11}	64.75 (0.452)	ϕ_{11}	-406.90 (-2.456 ***)
P12 *(13:30PM - 14:00PM)*	γ_{12}	-37.24 (-0.253)	δ_{12}	351.01 (2.913 ***)	θ_{12}	35.81 (0.256)	ϕ_{12}	-308.34 (-1.547 *)
P13 *(14:00PM - 14:30PM)*	γ_{13}	109.74 (0.478)	δ_{13}	-709.43 (-4.838 ***)	θ_{13}	-54.5 (-0.258)	ϕ_{13}	-743.95 (-2.478 ***)

This table reports the impact of market news on intraday volatilities (Panel A) and trading activities (Panel B). Market news considered includes Crude Oil Inventory Announcement (Column Two), Non-farm Payroll Report (Column Three), Natural Gas Inventory Report (Column Four) and IPCU Report (Column Five). Column one denotes consecutive intraday periods between 8:00AM to 14:30PM, spanning 30 minutes each, on announcement or release days of market news. The estimated model has the following form

$$v_i = \alpha + \sum_{k=1}^{13} \gamma_k D^{oil}{}_{i,k} + \sum_{k=1}^{13} \delta_k D^{nonfarm}{}_{i,k} + \sum_{k=1}^{13} \theta_k D^{gas}{}_{i,k} + \sum_{k=1}^{13} \phi_k D^{ipcu}{}_{i,k} + \varepsilon_i$$

where v_i is intraday volatility (Panel A) or number of trades (Panel B), corrected for weekday , trading hour and expiration shrinkage effects. $D_{i,k}^{oil} = 1$ when v_i is for period k on Wednesday (the day of crude oil inventory announcement), and 0 otherwise. $D_{i,k}^{nonfarm} = 1$ when v_i is for period k on day of Nonfarm Employment Payroll Report, and 0 otherwise. $D_{i,k}^{gas} = 1$ when v_i is for period k_on Thursday (the day of Natural Gas Inventory Report, and 0 otherwise. Sample contains 5-minute interval data of nearby crude oil futures of crude oil, spanning July, 2003 through December, 2011. Estimation is by OLS. Newey-West t-statistics are reported in parenthesis. The highlighted represents the results for the immediate subsequent period after the announcement or release of market news. *, **, *** indicate the significance at the 10%, 5% and 1% level, respectively.

Table 7. Definitions of Lagged Return and Lagged Volatility

	LaggedReturn $_i$	***LaggedVolatility*** $_{i,j}$
Overnight Period	intraday return between 9:00AM to 3:00PM on Tuesday of Week i	j = 1 intraday volatility between 9:00AM to 3:00PM on Tuesday of Week i
Preceding Period Before Announcement	intraday return between 9:00AM to 10:00AM on Wednesday of Week i	j runs from 1 to 2 1. intraday volatility between 9:00AM to 10:00AM on Wednesday of Week i 2. intrady volatility between 9:00AM to 3:00PM on Tuesday of Week i
Subsequent Period After Announcement	intraday return between 10:00AM to 10:35 AM on Wednesday of Week i	j runs from 1 to 2 1. intraday volatility between 10:00AM to 10:35AM on Wednesday of Week i 2. intrady volatility between 9:00AM to 3:00PM on Tuesday of Week i
Remaining Period	intraday return between 10:35AM to 11:00AM on Wednesday of Week i	j runs from 1 to 2 1. intraday volatility between 10:35AM to 11:00AM on Wednesday of Week i 2. intrady volatility between 10:00AM to 10:35AM on Wednesday of Week i

This table provides the definition of lagged return and lagged volatility included in Equation (16) for four intra-day trading periods: (1) overnight period (3:00PM on Tuesday to 10:00AM on Wednesday); (2) preceding period before announcement (10:00AM to 10:30AM on Wednesday); (3) subsequent period after announcement (10:35AM to 11:00AM on Wednesday); (4) remaining period after announcement (11:00AM to 3:00PM on Wednesday)

Table 8. Regression Results for Inventory Shock on Intraday Return

Panl A: Result for return of subsequent period after announcement (10:35AM to 11:00AM on Wednesday)			
	1	2	3
Intercept	-0.0005 (-1.3346)	0.0077 (1.8126)	0.0074 (1.7587)
Inventory Shock (10 million barrels)	-0.0007 (-0.6372)		-0.0017 (-1.3225)
Short Rate on Tuesday		-0.0465 (-2.4325)	-0.0446 (-2.3201)
Yield Spread on Tuesday		-0.0563 (-0.6626)	-0.0521 (-0.6188)
Basis on Tuesday		0.0003 (0.9748)	0.0003 (0.9419)
Intraday Return (10:00AM - 10:35AM on Wednesday)		-0.0786 (-1.5845)	-0.1086 (-1.8668)
Intraday Volatility (10:00AM - 10:35AM on Wednesday)		0.0017 (0.8701)	0.0017 (0.8367)
Intraday Volatility (9:00AM - 3:00PM on Tuesday)		-0.0203 (-4.4754)	-0.0201 (-4.5065)
Adjusted R square	0.001	0.078	0.082

Panl B: Result for return of the rest of the day (11:00AM to 3:00PM on Wednesday)			
	4	5	6
Intercept	0.0011 (1.3491)	-0.0116 (-1.1981)	-0.0114 (-1.1834)
Inventory Shock (10 million barrels)	0.0009 (0.3216)		0.0009 (0.3330)
Short Rate on Tuesday		-0.0533 (-1.1878)	-0.0539 (-1.2027)
Yield Spread on Tuesday		0.2589 (1.2983)	0.2568 (1.2897)
Basis on Tuesday		-0.0012 (-1.2260)	-0.0012 (-1.2391)
Intraday Return (10:35AM - 11:00AM on Wednesday)		-0.3075 (-1.9930)	-0.3073 (-1.9932)
Intraday Volatility (10:35AM - 11:00AM on Wednesday)		-0.0035 (-0.7500)	0.0017 (0.8367)
Intraday Volatility (10:00AM - 10:35AM on Wednesday)		0.0045 (0.9600)	0.0045 (0.9616)
Adjusted R square	0.000	0.038	0.039

Panl C: Result for return of preceding period before announcement (10:00AM to 10:35AM on Wednesday)			
	7	**8**	**9**
Intercept	-0.007 (-2.8374)	0.0036 (1.1123)	0.0026 (0.8018)
Inventory Shock (10 million barrels)	-0.0040 (-5.1828 ***)		-0.0039 (-5.2140 ***)
Short Rate on Tuesday		0.0340 (2.0780)	0.0355 (2.2341)
Yield Spread on Tuesday		-0.0953 (-1.4938)	-0.0801 (-1.2629)
Basis on Tuesday		-0.0006 (-1.7068)	-0.0006 (-1.5759)
Intraday Return (9:00AM - 10:00AM on Wednesday)		0.0122 (0.2160)	-0.0098 (-0.1881)
Intraday Volatility (9:00AM - 10:00AM on Wednesday)		0.0002 (0.0674)	-0.0002 (-0.0500)
Intraday Volatility (9:00AM - 3:00PM on Tuesday)		0.0018 (0.4661)	0.0025 (0.6648)
Adjusted R square	0.063	0.029	0.09

Panl D: Result for overnight return(3:00PM on Tuesday to 10:00AM on Wednesday)			
	10	**11**	**12**
Intercept	0.000 (0.0270)	0.0048 (0.4514)	0.0038 (0.3679)
Inventory Shock (10 million barrels)	-0.0042 (-2.4217 **)		-0.0042 (-2.4542 **)
Short Rate on Tuesday		0.0139 (0.4074)	0.0161 (0.4764)
Yield Spread on Tuesday		-0.1212 (-0.5973)	-0.1071 (-0.5382)
Basis on Tuesday		-0.0005 (-0.6666)	-0.0005 (-0.6154)
Intraday Return (9:00AM - 3:00PM on Tuesday)		0.0076 (0.1830)	0.0040 (0.0969)
Intraday Volatility (9:00AM - 3:00PM on Tuesday)		0.0069 (0.7906)	0.0072 (0.8394)
Adjusted R square	0.013	0.005	0.017

This table presents the estimate results of the impact of inventory shock on crude oil futures intraday return. The estimated model has the following form

$$r_{i,k} = \alpha + \beta \cdot invetnoryShock_i + \gamma_0 \cdot basis_i + \gamma_1 \cdot shortRate_i + \gamma_2 \cdot yieldSprd_i + \gamma_3 \cdot laggedReturn_i + \sum_{j=1}^{N} \theta_j \cdot laggedVolatility_{i,j} + \epsilon_i$$

The dependent variable is the intraday period return of nearby crude oil futures. Four intraday periods are considered: Panel A reports the result for the immediate subsequent period after crude oil inventory announcement (10:35AM to 11:00AM on Wednesday); Panel B reports the result for the remaining period after crude oil inventory announcement (11:00AM to 3:00PM on Wednesday); Panel C reports the result for immediate preceding period before crude oil inventory announcement (10:00AM to 10:30AM on Wednesday); Panel D reports the result for the overnight period (3:00PM on Tuesday to 10:00AM on Wednesday); The explanatory variables include *inventory shock*, defined as the difference between the realized inventory level and the best forecast by market; *short rate*, defined as U.S. one month Treasury rate; *yield spread*, defined as the difference between Moody's Aaa corporate bond yield and U.S. one month Treasury Bill rate; *lagged intraday return* and *lagged intraday volatility*, defined in table 7. Univariate model (1,4, 7 and 10) have *inventory shock* as explanatory variable. Model 2, 5, 8 and 11 include all explanatory variables except *inventory shock*. Model 3, 6,9 and 12 contain all explanatory variables. Sample contains 5-minute interval data of the nearby crude oil futures, spanning July, 2003 through December, 2011. Estimation is by OLS. Newey-West t-statistics are reported in parenthesis. *, **, *** indicate the significance at the 10%, 5% and 1% level, respectively.

Table 9. Regression Results for Inventory Shock on Intraday Basis Change

Panel A: Period at announcement (10:25AM to 10:35AM on Wednesday)									
Futures	**M2**	**M3**	**M4**	**M5**	**M6**	**M7**	**M8**	**M9**	**M10**
Intercept	0.0037 (0.4260)	-0.0182 (-1.4001)	-0.0122 (-0.7407)	-0.0036 (-0.2243)	-0.0019 (-0.1036)	-0.0217 (-1.0350)	0.0075 (0.3730)	-0.0019 (-0.0947)	-0.0065 (-0.3266)
InventoryShock (10milliion barrels)	0.0721 (2.5384 ***)	0.2211 (4.6821 ***)	0.3530 (6.3666 ***)	0.3707 (5.5048 ***)	0.5214 (6.5794 ***)	0.5342 (6.4726 ***)	0.6007 (7.7799 ***)	0.6140 (7.4820 ***)	0.6861 (8.4042 ***)
Adj. R^2	0.015	0.058	0.1	0.093	0.14	0.12	0.162	0.161	0.0195

Panel B: Period before announcement (9:00AM to 10:25AM on Wednesday)									
Futures	**M2**	**M3**	**M4**	**M5**	**M6**	**M7**	**M8**	**M9**	**M10**
Intercept	-0.0015 (-0.4055)	0.0069 (1.0372)	0.0256 (2.1049)	-0.0074 (-0.4339)	-0.0010 (-0.0557)	0.0178 (0.8500)	-0.0265 (-1.0568)	0.0391 (1.4394)	-0.0273 (-0.9578)
InventoryShock (10milliion barrels)	0.0311 (2.9210 ***)	0.0293 (1.5256 *)	0.036 (0.8621)	0.1404 (1.8369 *)	0.0985 (1.4371 *)	0.0924 (0.9754)	0.1192 (0.8860)	0.1527 (1.0904)	0.0676 (0.5557)
Adj. R^2	0.016	0.066	0.002	0.014	0.006	0.004	0.004	0.005	0.001

Panel C: Period after announcement (10:35AM to 11:00AM on Wednesday)									
Futures	**M2**	**M3**	**M4**	**M5**	**M6**	**M7**	**M8**	**M9**	**M10**
Intercept	0.0028 (0.3038)	0.0160 (1.1114)	0.0212 (1.0724)	0.0189 (0.9579)	0.0140 (0.4872)	0.0447 (1.7572)	0.0323 (1.1533)	0.0316 (1.2049)	0.0691 (2.4743)
InventoryShock (10milliion barrels)	-0.0266 (-0.9719)	-0.1361 (-2.4687 ***)	-0.2048 (-2.6272 ***)	-0.1698 (-2.2998 **)	-0.1852 (-2.3228 **)	-0.1014 (-1.1985)	-0.0889 (-0.9364)	-0.1935 (-1.9597 **)	-0.1311 (-1.2496)
Adj. R^2	0.002	0.016	0.023	0.015	0.01	0.004	0.002	0.012	0.005

This table presents the estimate results of the impact of inventory shock on crude oil futures basis change in intraday periods. Three intraday periods are considered: Panel A reports the results for the period spanning the announcement (10:25AM to 10:35AM on Wednesday); Panel B reports the result for the period before the announcement (9:00AM to 10:25AM on Wednesday); Panel C reports the results for the period after the announcement (10:35AM to 11:00AM on Wednesday). The nearby contract is used as a proxy for spot. Basis changes are calculated for the next 9 near contracts with maturities up to one year, denoted as M2, M3…, M10. The estimated model has the following form

$$BasisChg_{i,k,m} = \alpha + \beta \cdot inventoryShock_i + \varepsilon_i$$

where $BasicChg_{i,k,m}$ is basis change of futures *m* in period *k* on Wednesday of week *i*. Sample contains 5-minute interval data of the nearby crude oil futures as well as the next 9 near futures , spanning July, 2003 through December, 2011. Estimation is by OLS. Newey-West t-statistics are reported in parenthesis. *, **, *** indicate the significance at the 10%, 5% and 1% level, respectively.

Table 10. Regression Results for Contemporaneous Volatility-Volumes Relation

Panel A: Continous Component of Realized Volatility						
	All-week-day	**Mon**	**Tue**	**Wed**	**Thu**	**Fri**
whole period: July 1, 2003 - Dec 31, 2011						
# of observation	**2169**	**424**	**440**	**444**	**437**	**424**
coefficient of volume	0.0022	0.0027	0.0012	0.0009	0.0028	0.002
t_NW	3.639 ***	3.246 ***	3.032 ***	2.486 ***	4.248 ***	2.9691 ***
adj R^2	75.3%	74.4%	76.4%	84.5%	75.6%	80.6%
sub-period I: July 1, 2003 - Dec 31, 2005						
# of observation	**625**	**118**	**130**	**131**	**126**	**120**
coefficient of volume	0.05	0.05	0.04	0.03	0.03	0.03
t_NW	3.839 ***	1.6041 *	3.485 ***	1.19	0.579	1.099
adj R^2	31.3%	46.5%	33.3%	46.5%	21.2%	45.4%
sub-period II: Jan 1, 2006 - Dec 31, 2007						
# of observation	**511**	**99**	**102**	**104**	**104**	**102**
coefficient of volume	0.0022	0.0016	0.0007	0.0027	0.0025	0.0024
t_NW	5.841 ***	2.301 **	1.814 **	3.55 ***	3.398 ***	3.754 ***
adj R^2	46.1%	51.1%	54.8%	60.0%	47.2%	53.3%
sub-period III: Jan 1, 2008 - Dec 31, 2009						
# of observation	**517**	**104**	**104**	**105**	**103**	**101**
coefficient of volume	0.0071	0.0065	0.0038	0.0024	0.0084	0.01
t_NW	2.417 ***	3.129 ***	1.406 *	1.642 *	2.502 ***	1.912 **
adj R^2	75.5%	73.1%	78.7%	85.7%	81.2%	84.4%
sub-period IV: Jan 1, 2010 - Dec 31, 2011						
# of observation	**516**	**103**	**104**	**104**	**104**	**101**
coefficient of volume	0.0029	0.0026	0.003	0.002	0.0033	0.0015
t_NW	7.687 ***	6.063 ***	9.065 ***	3.969 ***	4.121 ***	3.213 ***
adj R^2	52.0%	64.4%	43.8%	75.2%	62.9%	68.4%

Panel B: Jump Component of Realized Volatility						
	All-week-day	**Mon**	**Tue**	**Wed**	**Thu**	**Fri**
whole period: July 1, 2003 - Dec 31, 2011						
# of observation	**2169**	**424**	**440**	**444**	**437**	**424**
coefficient of volume	0.0009	0.0006	0.0005	0.00005	0.00116	0.0005
t_NW	5.651 ***	3.237 ***	2.5 ***	0.165	4.784 ***	1.24
adj R^2	9.1%	12.2%	13.6%	30.3%	13.0%	9.3%
sub-period I: July 1, 2003 - Dec 31, 2005						
# of observation	**625**	**118**	**130**	**131**	**126**	**120**
coefficient of volume	0.0061	-0.0097	-0.001	-0.0077	-0.0112	0.031
t_NW	0.76	-0.69	-0.16	-0.24	-0.71	2.196 **
adj R^2	10.8%	15.2%	3.8%	16.9%	15.5%	18.7%
sub-period II: Jan 1, 2006 - Dec 31, 2007						
# of observation	**511**	**99**	**102**	**104**	**104**	**102**
coefficient of volume	0.0013	0.0005	0.0003	0.0024	0.0015	0.0007
t_NW	5.841 ***	2.301 **	1.814 **	3.55 ***	3.398 ***	3.754 ***
adj R^2	46.1%	51.1%	54.8%	60.0%	47.2%	53.3%
sub-period III: Jan 1, 2008 - Dec 31, 2009						
# of observation	**517**	**104**	**104**	**105**	**103**	**101**
coefficient of volume	0.0004	0.0003	0.001	-0.0037	0.0016	-0.0027
t_NW	0.493	0.315	1.519 *	-1.9003 **	2.778 ***	-0.789
adj R^2	75.5%	73.1%	78.7%	85.7%	81.2%	84.4%
sub-period IV: Jan 1, 2010 - Dec 31, 2011						
# of observation	**516**	**103**	**104**	**104**	**104**	**101**
coefficient of volume	0.0006	0.0009	0.0002	0.0001	0.0008	0.0001
t_NW	6.34 ***	5.848 ***	1.86 **	0.721	3.351 ***	0.385
adj R^2	5.9%	26.9%	8.1%	13.3%	13.6%	9.5%

This table presents the results of the contemporaneous relation between volatility and volume in crude oil futures market. Panel A and B report the estimates of the following regression models, respectively

$$CRV_t = \beta_0 + \textstyle\sum_{k=1}^{12} \beta_k \cdot CRV_{t-k} + \theta \cdot v_t + \varepsilon_t$$

$$JRV_t = \beta_0 + \sum_{k=1}^{12} \beta_k \cdot JRV_{t-k} + \theta \cdot v_t + \varepsilon_t$$

where CRV_t is the continuous component of realized variance, JRV_t is the jump component of realized variance, v_t is the trading volume corrected for trending and expiration shrinkage effects. All volatility measures are annualized. Trading volumes are scaled by 10,000. Sample contains 5-minute interval data of the nearby crude oil futures, spanning July, 2003 through December, 2011. For sub-periods are considered: July 1, 2003 through Dec 31, 2005; Jan 1, 2006 through Dec 31, 2007; Jan 1, 2008 through Dec 31, 2009; Jan 1, 2010 through Dec 31, 2011. Estimation is by OLS. The coefficient of trading volume and Newey-West t-statistics are reported. *, **, *** indicate the significance at the 10%, 5% and 1% level, respectively.

Table 11. Volatility-Volume (or Number of Trades) relation between 10:30AM and 11:00AM

dependent variable: abs(log return) 10:30AM to 10:35AM	**Wednesday**				**Other WeekDays**			
	Jump Process		**Continuous Process**		**Jump Process**		**Continuous Process**	
Volume (10:35AM to 11:00AM)	**-0.0002 (-0.6446)**		**0.0003 (2.3398 ***)**		**0.0009 (2.2160 ***)**		**0.0001 (1.1944 *)**	
Number of Trades (10:35AM to 11:00AM)		**-0.0008 (-1.5139 **)**		**0.0005 (2.0814 ***)**		**0.0017 (1.5591 **)**		**0.0002 (1.4165 *)**
1 lagged dep. var.	0.2120 (1.5368 **)	0.2324 (1.6991 **)	0.0561 (0.6977)	0.0574 (0.7143)	0.4359 (2.3589 ***)	0.4189 (2.2881 ***)	0.1112 (3.3474 ***)	0.1109 (3.3412 ***)
2 lagged dep. var.	0.1279 (0.4194)	0.1009 (0.3334)	0.1092 (1.1153 *)	0.1124 (1.1442 *)	-0.0940 (-0.3590)	-0.1124 (-0.4287)	0.0725 (2.4055 ***)	0.0722 (2.3974 ***)
3 lagged dep. var.	0.2887 (0.8964)	0.2656 (0.8263)	0.0784 (0.6579)	0.0788 (0.6607)	0.2819 (1.9802 **)	0.3027 (2.1044 ***)	0.0997 (3.0033 ***)	0.0996 (3.0010 ***)
4 lagged dep. var.	0.7163 (1.7681 **)	0.6742 (1.6687 **)	-0.1592 (-1.8318 **)	-0.1688 (-1.9455 **)	-0.2120 (-0.6975)	-0.1705 (-0.5304)	0.0645 (2.2076 ***)	0.0647 (2.2171 ***)
5 lagged dep. var.	0.1414 (0.6430)	0.1464 (0.6611)	0.3227 (2.6794 ***)	0.3201 (2.6534 ***)	0.1914 (0.9230)	0.1719 (0.8202)	0.1236 (5.2917 ***)	0.1237 (5.3001 ***)
6 lagged dep. var.	0.2069 (0.8754)	0.1804 (0.7613)	0.1326 (1.5993 **)	0.1351 (1.6340 **)	-0.1203 (-0.7097)	-0.0912 (-0.5382)	0.0399 (1.3493 *)	0.0398 (1.3448 *)
Adj. R^2	0.077	0.083	0.094	0.09	0.378	0.355	0.124	0.124

This table presents the results of relation between the absolute 5-minute log return at 10:35AM and volume (or number of trades) in the subsequent period (10:35AM to 11:00AM). The estimated model has the following form

$$absRet_t^J = \alpha + \beta \cdot V_t + \sum_{k=1}^{6} \gamma_k \cdot absRet_{t-k} + \varepsilon_t$$

$$absRet_t^J = \alpha + \beta \cdot N_t + \sum_{k=1}^{6} \gamma_k \cdot absRet_{t-k} + \varepsilon_t$$

$$absRet_t^C = \alpha + \beta \cdot V_t + \sum_{k=1}^{6} \gamma_k \cdot absRet_{t-k} + \varepsilon_t$$

$$absRet_t^C = \alpha + \beta \cdot N_t + \sum_{k=1}^{6} \gamma_k \cdot absRet_{t-k} + \varepsilon_t$$

where the dependent variable $absRet_t^J$ ($absRet_t^C$) is the absolute 5-minute log return observed at 10:35AM when the past 5 minutes price move is identified as a jump process (continuous process). V_t (N_t) is the trading volume (number of trades) in the subsequent period between 10:35AM to 11:00AM, corrected for trending and expiration shrinkage effects and scaled by 10,000. Six lagged absolute 5-minute log returns are included to account for persistency. Sample contains 5-minute interval data of the nearby crude oil futures, spanning July, 2003 through December, 2011. Other weekdays contains data on Monday, Tuesday and Friday. Estimation is by OLS. Newey-West t-statistics are reported in parenthesis. *, **, *** indicate the significance at the 10%, 5% and 1% level, respectively.

Table 12. Descriptive Statistics of Risk Neutral Momentum Measurement

Year	RNJV			RN Holding Period Variance			RN Skewness			RN Kurtosis		
	P5	P50	P95	P5	P50	P95	P5	P50	P95	P5	P50	P95
2004	-0.03%	0.22%	0.43%	0.3052	0.3547	0.392	-0.7719	-0.4742	0.0362	3.639	5.7092	8.4492
2005	-0.04%	0.11%	0.15%	0.3421	0.3896	0.4527	-0.2225	-0.126	0.0483	3.2287	3.3299	3.9866
2006	-0.38%	0.03%	0.12%	0.2565	0.2922	0.3292	-0.2912	-0.0904	0.8906	3.5148	3.8921	9.8406
2007	-0.25%	0.07%	0.16%	0.264	0.3022	0.3938	-0.3918	-0.1462	0.3439	3.4696	4.6052	6.8575
2008	-0.17%	0.05%	0.72%	0.3053	0.4434	0.9672	-0.2796	-0.0751	0.2429	3.3366	3.7633	4.7849
2009	0.17%	0.69%	1.10%	0.3943	0.4917	0.8698	-0.8574	-0.4856	-0.2065	3.5104	4.3452	6.7627
2010	0.05%	0.26%	0.58%	0.2823	0.3265	0.4278	-0.7893	-0.5799	-0.1495	4.496	5.0513	7.095
Aggregate	-0.19%	0.11%	0.80%	0.2707	0.3422	0.8085	-0.7447	-0.2281	0.2786	3.4373	4.3063	7.1018

This table presents the 5th percentile, median, and 95th percentiles of risk neutral jump variance (RNJV), holding period variance, skewness and kurtosis by year. All reported risk neutral momentums are estimated for the synthetic 30-days maturity using daily options on crude oil future, spanning Jul 1, 2003 through Dec 31, 2010. For each business day, we construct the risk neutral momentum for two maturities that are most close to 30-days, and interpolate the corresponding risk neutral momentum for the synthetic 30-days maturity. We follow the procedure in Bakshi, Kapadian, and Madan (2003) to calculate the risk neutral holding period variance (Equation (9)), skewness (Equation (25)) and kurtosis (Equation (26)), and use Equation (9), (10) and (11) to calculate RNJV.

Table 13. Correlations Among Risk Neutral Momentum

Correlation	RN Holding Period Variance	RNJV
RN Skewness	-0.1335	-0.7591

This table presents the sample correlation among risk neutral jump variance (RNJV), skewness and holding period. All risk neutral metrics are estimated for the synthetic 30-days maturity.

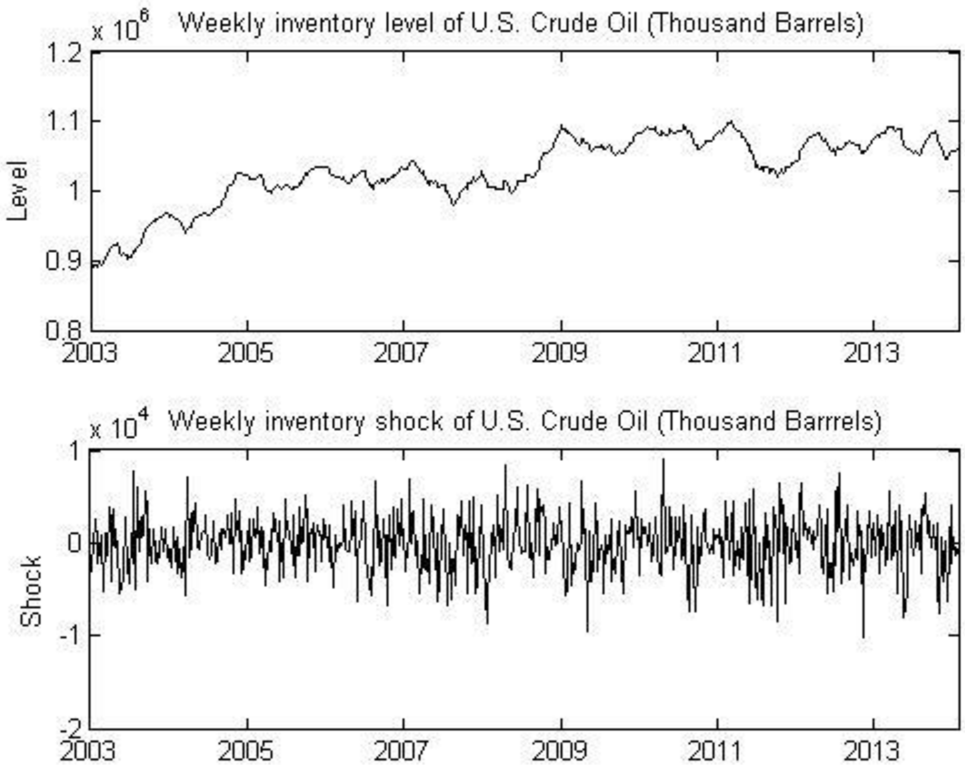
Table 14. Mean and Median of Risk Momentum by day-of-the-week

	RNJV		RN Holding Period Variance		RN Skewness		RN Kurtosis	
	mean	**median**	**mean**	**median**	**mean**	**median**	**mean**	**median**
Mon	0.21%	0.11%	0.4135	0.3529	-0.2445	-0.2286	4.6092	4.3585
Tue	0.21%	0.12%	0.4119	0.3503	-0.2508	-0.2364	4.6508	4.3477
Wed	0.20%	0.11%	0.4085	0.3502	-0.2406	-0.2252	4.6828	4.4671
Thur	0.19%	0.11%	0.4017	0.3465	-0.2314	-0.2227	4.7487	4.4706
Fri	0.21%	0.11%	0.4023	0.3425	-0.238	-0.224	4.7065	4.4184

This table presents the sample mean and median of risk neutral jump variance, holding period variance, skewness and kurtosis, estimated for the maturity of options on nearby crude oil futures, by day-of-the-week. All reported risk neutral momentums are estimated using daily options on nearby crude oil futures, spanning Jul 1, 2003 through Dec 31, 2010.

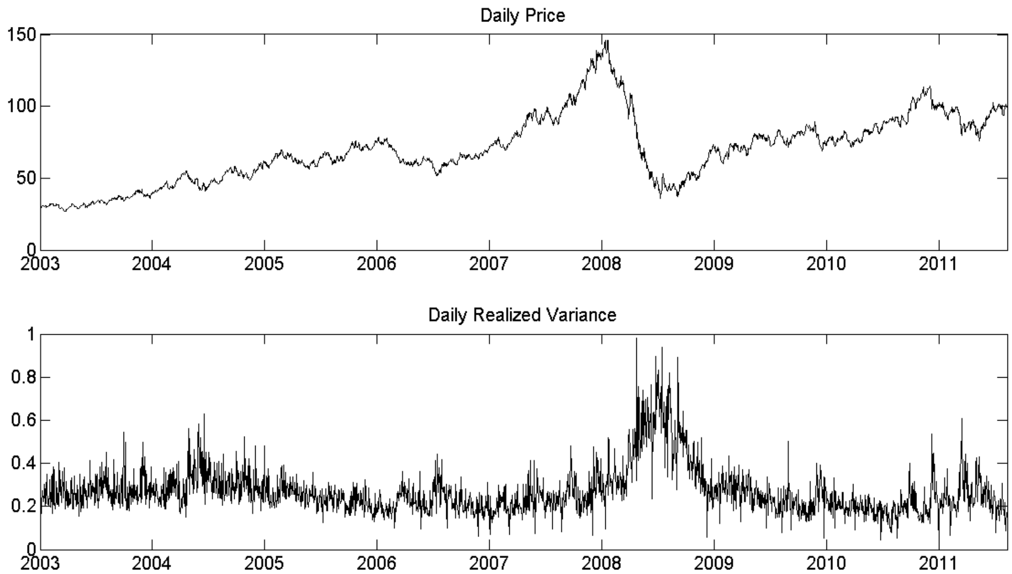
Figures

Fig 1. Weekly U.S. ending inventory level and shocks of crude oil



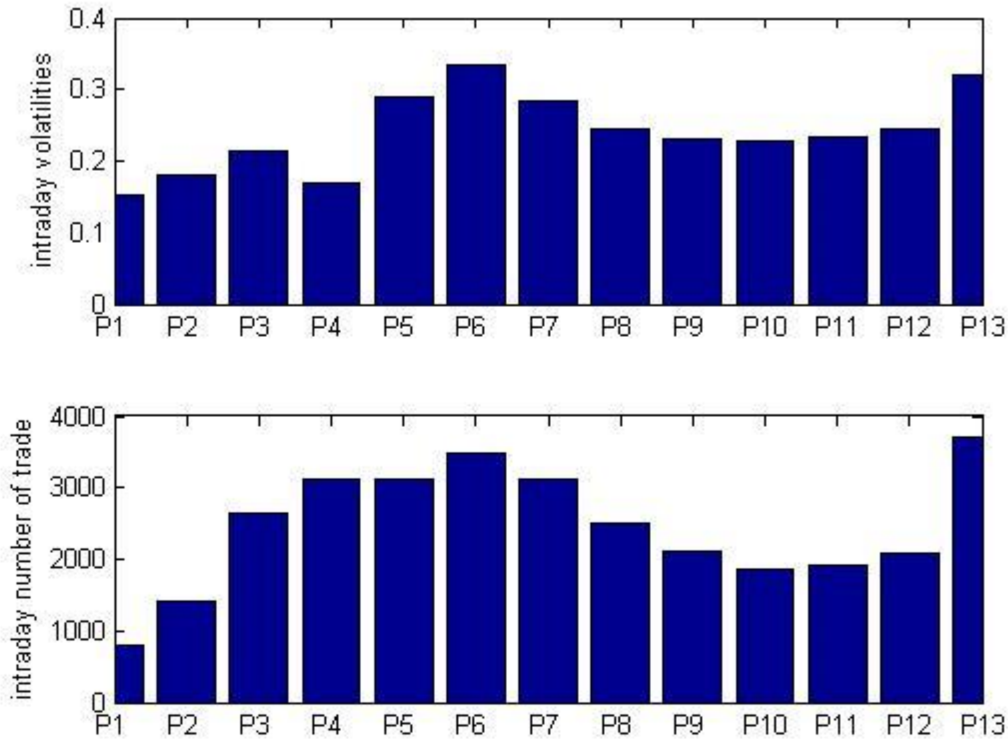
This plot presents the weekly ending inventory level and shocks of crude oil. The level data is obtained from EIA's website , covering 565 weeks from July, 2003 to March, 2014 , . The shock is defined as the difference between the realized inventory level and the best forecast by market. On each Friday, a survey for next week's inventory level is drawn from a few highly reputed analysts. We obtain the survey data from Bloomberg and take the median number as the best forecast by market.

Fig 2. Daily price and realized variance of nearby crude oil futures



This figure plots the time series of the daily price and realized variance (annualized and in standard deviation form) of nearby crude oil futures for period from July, 2003 to Dec 31, 2011. For each business day, the price is sampled at 2:30PM, and the realized variance is calculated using 5-minutes interval price series for open cry period (9:00AM – 2:30PM).

Fig 3. Trading Hour Effect on Intraday Volatilities and Trading Activities

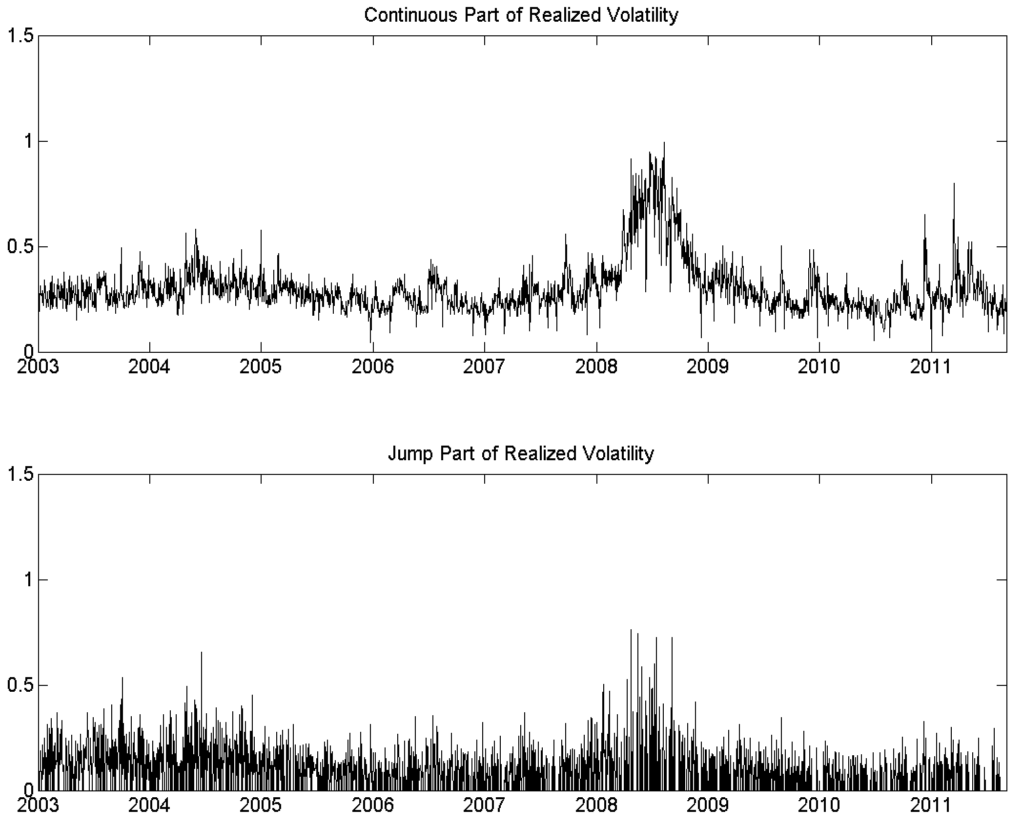


This figure shows the trading hour effect of intraday volatilities and trading activities. 13 consecutive intraday periods between 8:00AM and 2:30PM are considered, spanning 30 minutes each, and are denoted as P1, P2, P3…, P13. The estimated model has the following form

$$\omega_i = \sum_{k=1}^{13} \beta_k DummyHour_{i,k} + \upsilon_i$$

where ω_i is the intraday volatility or number of trades for an intraday period, corrected for weekday and expiration shrinkage effects. $DummyHour_{i,k}$ = 1 when ω_i is a measure for intraday period P(k). Top (Bottom) panel plots the coefficients β_s of dummy variables, normalized by adding back sample mean of intraday volatility (number of trades), representing the average intraday volatilities (number of trades) in corresponding periods. Estimation is by OLS.

Fig 4. Decomposition of Realized Volatility of Crude Oil Futures



The top panel plots the time series of continuous component of realized volatility (annualized). The bottom panel plots the time series of jump component of realized volatility (annualized). The realized volatility is estimated by Equation (2) using the 5-minutes interval price series of nearby crude oil futures, spanning July 1, 2003 through Dec 31, 2011. Jumps in price series are detected using the technique described in sections 3.3. Realized volatilities are decomposed into continuous component and jump component, using the method described in section 3.2.

Reference

Andersen, T.G. (1996), "Return volatility and trading volume: an information flow interpretation of stochastic volatility," *Journal of Finance* 51:169-204.

Andersen, T.G. and Bollerslev, T. (1998a), "Answering the skeptics: Yes, standard volatility models do provide accurate forecasts," *International Economic Review* 39:885-905.

Andersen, T.G., Bollerslev, T., Diebold, F.X., and Ebens, H. (2001), "The distribution of realized stock return volatility," *Journal of financial Economics* 61:43-76.

Ane, T., and Geman, H. (2000), "Order flow, transaction clock, and normality of asset returns," *Journal of Finance* 55:2259-2284.

Bakshi, G., Kapadia, N, and Madan, D. (2003), "Stock Return characteristics, Skew Laws, and the Differential Pricing of Individual Equity Options," *Review of Financial Studies* 16:101-143.

Barndorff-Nielsen, O. and Shephard, N. (2004), "Power and bipower variation with stochastic volatility and jumps," *Journal of Financial Econometrics* 2:1-37.

Barndorff-Nielsen, O. and Shephard, N. (2006), "Econometrics of testing for jumps in financial economics using bipower variation," *Journal of Financial Econometrics* 4:1-30.

Barndorff-Nielsen, O. and Shephard, N. (2002), "Econometric analysis of realized volatility and its use in estimating stochastic volatility models," *Journal of the Royal Statistical Society Series* B64:253-280.

Barone-Adesi, G. and Whaley, R. (1987), "Efficient analytic approximation of American option values," *Journal of Finance* 42:301-320.

Carr, P. and Wu, L. (2009), "Variance Risk Premiums," *Review of Financial Studies* 22:1311-1341.

Chevallier, J. and Sevi, B. (2012), "On the volatility-volume relationship in energy futures markets using intraday data," *Energy Economics* 34:1896-1909.

Chiou-Wei, S.Z, Linn, S.C and Zhu, Z (2013) "The response of U.S. natural gas futures and spot prices to storage change surprises and the effect of escalating physical gas production," working paper.

Clark, P.K. (1973), "A subordinated stochastic process model with finite variance for speculative prices," *Econometrica* 41:135-155.

Du, J. and Kapadia, N. (2011), "The tail in the volatility index," working paper.

Duan, J.C. and Wei, J. (2009), “Systematic risk and the price structure of individual equity options,” *Review of Financial Studies* 22:1981-2006.

Elder, J., Miao, H., and Ramchander, S. (2013), "Jumps in oil prices: the role of economic news," *Energy Journal* 34:217-237.

Epps, T.W. (1975), “Security price changes and transaction volumes: theory and evidence,” *American Economic Review* 65:586-597.

Fama, E. (1965), “The behavior of stock market prices,” *Journal of Business* 38:34-105.

Figlewski, S. and Birru, J. (2010), “The impact of the Federal Reserve’s interest rate target announcement on stock prices: a closer look at how the market impounds new information,” working paper.

Gallant, R., Rossi, P., and Tauchen, G. (1992), “Stock prices and volume,” *Review of Financial Studies* 5:199-242

Gatheral J. (2004), “A parsimonious arbitrage-free implied volatility parameterization with application to the valuation of volatility derivatives,” *Presentation in Madrid*.

Giot, P., Laurent, S. and Petitjean, M. (2010), “Trading activity, realized volatility and jumps,” *Journal of Empirical Finance* 17:168-175.

Gorton, G., Hayshi, F., and Rouwenhorst, G. (2012), “The fundamentals of commodity futures returns,” *Review of Finance* 17:35-105.

Halva, M.W, Kurov, A. and Kucher, O. (2013), “Noisy inventory announcements and energy prices” *Journal of Futures Markets*, forthcoming.

Hansen, P.R. and Lunde, A. (2006), “Realized variance and market microstructure noise,” *Journal of Business and Economic Statistics* 24:12-161.

Harris, L. (1987), “Transaction data tests of the mixture of distribution hypothesis,” *Journal of financial and Quantitative Analysis* 22:127-141.

Heston, S.L, Korajczyk, R.A., Sadka, R. and Thorson, L.D. (2010), “Are you trading predictably?” *SSRN eLibrary, 2010*

Hicks, J.R. (1939), “Value and capital” (Cambridge, England: Oxford University Press).

Hirshleifer, D.(1989), “Determinants of hedging and risk premia in commodity futures markets,” *Journal of Financial and Quantitative Analysis* 24:313-331.

Hong, H.G. and Yoho, M.(2010), “Commodity Market Interest nd Asset Return Predictability” *SSRN eLibrary, 2010*

Kaldor, N. (1939), “Speculation and Economic Stability,” *Review of Economic Studies* 7: 1-27.

Karpoff, J. (1987), “The relationship between price changes and trading volume: a survey,” *Journal of Finance and Quantitative Analysis* 22:109-126.

Keynes, J.M. (1930), “A Treatises on Money” vol.2 (London: Macmillan).

Lee, S.S. (2012), “Jumps and information flow in financial markets,” *Review of Financial Studies* 25:439-479.

Lee, S.S. and Mykland, P.A. (2008), “Jumps in financial markets: a new nonparametric test and jump dynamics,” *Review of Financial Studies* 21:2535-2563.

Linn, S.C. and Zhu, Z. (2003), “Natural gas prices and the gas storage report: public news and volatility in energy futures markets,” *The Journal of Futures Markets* 24:283-313.

Pearch, D. K. and V. V. Roley (1985), “Stock prices and economic news,” *Journal of Business* 58:49-67

Roseman, R. and Wolfe M.H. (2014), “Bidirectional causality in oil and gas markets,” *Energy Economics, forthcoming*.

Rouwenhorst, K.G., and Tang, K. (2012), "Commodity investing," *Annual Review of Financial Economics* 4: 447-467.

Tauchen, G., and Pitts, M. (1983), “The price variability-volume relationship on speculative markets,” *Econometrica* 59:371-396.

Wang, T. and Huang, Z. (2012), “The relationship between volatility and trading volume in the Chinese stock market: A volatility decomposition perspective,” *Annals of Economics and Finance* 13-1:211-236.

Working, H. (1949), “The theory of the price of storage,” *American Economic Review* 39:1254-62.