# The inventory change surprise's role in energy price behaviour

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**Abstract:** In this paper, we investigate how the inventory announcements through information surprises affect energy commodity prices on return and volatility using a daily data from 9 November 2010 to 24 September 2013. The data set covers 150 inventory news released by the Energy Information Administration (EIA) for each commodity. Across a range of specifications, we find strong evidence for the negative effect of inventory surprises on energy commodity futures returns on the day of the announcement. In contrast, the effect after the announcement day becomes insignificant. Moreover, in separating inventory announcements into positive and negative surprises, we find that asymmetric responses in returns to EIA inventory shocks are pronounced for energy commodity. Finally, we show that natural gas volatility is susceptible to both positive and negative inventory surprises, whereas surprises do not matter for crude oil volatility.

**Keywords:** inventory surprises; energy commodity; futures prices; conditional volatility.

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## 1 Introduction

There is still an ongoing debate on whether news impact energy markets. A large literature focused on whether non-oil-specific news has an impact on oil prices. For instance, Barsky and Kilian (2002) argue that the oil price increases appear to be strongly related to global monetary conditions. Rosa (2014) reports that hypothetical unanticipated increase in the current federal funds target rate by 100-basis-point leads to a sharply fell in West Texas Intermediate (hereafter, WTI) crude oil prices by roughly 3%. Moreover, Basistha and Kurov (2015) document a negative and highly significant reaction of energy prices to monetary surprises within an intraday window around a given announcement. More recently, Chebbi (2018) finds that US unconventional monetary policy shocks have a significant impact on the WTI crude oil prices both on return and volatility. However, the existing literature has not yielded conclusive evidence. For example, using daily data, Kilian and Vega (2011) find no evidence of the effect of the surprise components of several US macroeconomic announcements on crude oil prices. Chatrath et al. (2012) and more recently Chan and Gray (2017) extend Kilian and Vega's (2011) study and they find that crude oil remains unresponsive to macroeconomic news.

Apart from the non-energy commodity-specific announcements, there has been substantial research on the effect of inventory news on energy prices. The inventory announcements are known to be one of the fundamental determinants of the oil price movements. The news on inventory not only conveys information about supply and demand conditions, but it also reflects pressures of changing market fundamentals on crude oil prices in short run. Therefore, news regarding energy inventory should reveal new information and requires investigation.

The link between inventory level and oil prices appears to be well established (see, e.g., early studies by Deaton and Laroque (1996), Pindyck (2004), Geman and Nguyen (2005), and more recently papers by Kilian and Murphy (2013), Kilian and Lee (2014), Smith et al. (2015) and Knittel and Pindyck (2016), among many others). Possible impacts of natural gas inventory reports have been also documented in the literature. For instance, Linn and Zhu (2004) investigated the effect of the EIA's weekly natural gas storage announcements on the natural gas price volatility. They find that the intraday volatility around the release time of reports is considerably greater than its normal level.

In the literature several theories are used to identify the different mechanisms of price determination. For instance, the "old consensus" in the literature was that the efficient market hypothesis which claims that asset prices reflect all publicly available information at any point in time and adjust to incorporate new information. Furthermore, considering the fact that futures markets are efficient, commodity futures prices should react to the surprise component in inventory levels embedded in public announcements. Another argument consistent with the efficient market hypothesis, indicating that only the surprise component of inventory announcements matters,[1] whereas the expected component ("old information") has already been built into market participants' price forecasts (Wolfe and Rosenman, 2014). The literature includes, in addition to the efficient market theory, the theories of storable commodities' prices which suggest that shocks to demand and supply conditions may result in price shifting around the mean (Deaton and Laroque, 1992, 1996; Routledge et al., 2000, among others.). A related theoretical literature includes the model for futures contracts on commodities by Black (1976) and McDonald (2013) which recognise that the price of a futures contract at time $t$, that calls for delivery at time $T$ equals the current spot price depending on the cost of storage, the interest rate and the convenience yield. A change in beliefs about supply and demand conditions induces a change in both the spot and futures prices. This argument is consistent with the idea that the current reported change in the amount of commodity in storage relative to expected changes should reveal fundamental information regarding changes in supply and demand conditions that in turn led to changes in the commodity prices.

Commodity price volatility can be related to uncertainty in demand, supply, and inventories. In particular, volatility are likely to respond to unexpected inventory changes as they can be considered as new information to investors, which can lead, in turn, to an increased market volatility through its effect on trading activity. This news obligates investors to rebalance their portfolios more intensively between assets thus spurring an increase in trading volume. As evidenced by the well-known positive relation between volatility and trading volume (Andersen, 1996; Karpoff, 1987, among others), the increase in trading volume could, in turn, translate into higher volatility. Another possible explanation, Ross (1989) attributes the increase in volatility in asset returns to information flow. Thus, it is important to study the response of volatility to inventory surprise for several reasons. First, understanding the volatility dynamics could create arbitrage opportunities for traders given that volatility is a central component in derivative pricing (Lee and Zyren, 2007). Second, the knowledge of the commodity volatility drivers is important for investors looking to optimise portfolio choices and for producers making supply-chain decisions (Smales, 2017).

Currently, there have been only few studies on the impact of surprise component in the inventory announcement on price movement and volatility. Chang et al. (2009) used analysts' forecasts from Bloomberg to explore the reactions of intraday crude oil futures returns to unexpected inventory changes. They find an immediate response of crude oil returns to inventory news. Moreover, they argued that the reaction is larger when the survey was made by analysts with forecast accuracy in the past. Gay et al. (2009) find that the unexpected changes in EIA's natural gas inventory reports have a significant impact on intraday futures returns immediately after a given announcement. By using a generalised autoregressive conditional heteroskedasticity (GARCH) model, Hui (2014) attempts to assess the impact of the unexpected inventory changes in the EIA report on daily crude oil returns and volatility. He finds that inventory shocks have negative impact on returns but suggests that there is no evidence of effect on return volatility. Chiou-Wei et al. (2014) examined the dynamics of US natural gas futures and spot prices around the weekly announcements by the EIA reports. Results highlight an inverse relation between the unexpected inventory changes and changes in futures prices. In addition, the authors find no evidence of the effect of inventory shocks other than on the date when the EIA report is released. Halova et al. (2014) looked at intraday data to investigate the impact of the unexpected part in EIA's crude oil inventory reports on both return and volatility. They find that energy returns respond more strongly to unexpected changes in inventory levels during the injection season than during the withdrawal season. Recently, Ye and Karali (2016) used intraday data to study the response of crude oil returns and volatility to inventory releases by the American Petroleum Institute (API) and EIA over the short August 2012 – December 2013 time period. They document that inventory shocks in both API and EIA reports exert an immediate inverse impact on returns and a positive impact on volatility. Miao et al. (2018) investigated the effect of the unexpected part of weekly crude oil inventory in EIA reports on oil futures and options prices. They show that prices strongly react to the inventory surprise on announcement day. Moreover, they find that futures returns significantly decrease with positive surprises and increase with negative surprises.

This paper is closely related to the literature studying the factors affecting the behaviour of energy market prices, and more especially those related to inventory announcements. In particular, we attempt to shed further light on the effects of the information shocks defined as the difference between the actual inventory changes released in the EIA weekly reports and market survey on the energy futures markets. These shocks provide an excellent opportunity to learn about storage information effects, specifically on return and volatility for several reasons. In fact, incorporating news regarding the market fundamentals, and more specifically, the unexpected part in inventory announcements to market expectations carry information relevant for price discovery in energy commodity futures markets. From a modelling perspective, the knowledge of such inventory news could contribute to better assess the energy price dynamics.

The contributions of this paper are threefold. First, in contrast to most existing studies focusing on the inventory itself, we look at the inventory information shocks or news to market expectations about the inventory. In particular, to extract inventory shocks, we use the difference between the actual inventory change released in the EIA reports and the consensus forecast of analysts' predictions developed by Reuters. We follow Miao et al. (2018) and divide this difference by its unconditional standard deviation to obtain standardised inventory surprise around each announcement event.

Second, we assess the response of energy prices to inventory surprises through GARCH based model of conditional return volatility. More specifically, the effect of changes in the surprise component of inventory announcements, on prices need not be limited to returns and can extend to volatility. This current paper allows positive and negative shocks to have asymmetric impacts on both futures return (Hui, 2014; Ye and Karali, 2016) and variance (Hui, 2014; Wolfe and Rosenman, 2014[2]; Ye and Karali, 2016).

Third, the current paper contributes to the larger debate on the determinants of energy prices by examining whether, and to what extent, the economic news affects energy prices. More specifically, this paper relates to empirical studies quantifying the effect of inventory levels to energy prices (e.g., Kilian and Lee (2014), Smith et al. (2015) and Knittel and Pindyck (2016) for the oil prices and Linn and Zhu (2004) for the natural gas prices). On the other hand, the papers that come closest to our research are the studies by Hui, et al. (2014), Ye and Karali (2016) and Chiou-Wei et al. (2014). While the first two papers focus on the impact of crude oil inventory surprises, the third refers to natural gas inventory surprises. However, we differentiate our work by examining the two energy markets, namely crude oil and natural gas based on EGARCH model which as argued in the literature seems to be well suited to explain volatility asymmetry and allows negative volatility coefficients (Booth et al., 1997; Braun et al., 1995) and based on a standardised surprise component of the inventory. We also introduce the magnitude of inventory surprise in the mean and variance equations in different ways. Finally, this paper employs daily data rather than an intraday window around the announcement day. The intraday data induces futures prices to react only to inventory news and not to extraneous information. However, the use of intraday data is potentially questionable. Specifically, we think that the announcement of the inventory report is complicated, and it could take some time for the market to digest such news.

In this paper, interesting evidences emerge and are summarised as follows. The results present evidence that surprises from EIA inventory reports may have significant effects on the energy commodity returns. A decrease in the inventory shock is associated with an increase in the oil price return. Thus, these results provide supportive evidence for the efficient markets hypothesis in the energy futures markets in that prices react to the unexpected news, namely the surprise component in the inventory levels embedded in public announcements by EIA reports. Second, we find evidence of the heterogeneity in the responsiveness of futures prices between the event day the EIA report is released and the days after the announcement. Third, in separating inventory announcements into positive and negative surprises, we find that asymmetric responses in returns to EIA shocks are pronounced for energy commodity inventory shocks. More specifically, we find that positive surprise has a significant negative effect on returns, while negative surprise is insignificant. When the EIA inventory experiences an unexpected increase, the futures prices tend to decrease. We confirm results from previous literature showing no evidence of significant responses of crude oil volatility to inventory announcements, and namely their associated surprises (Hui, 2014) on a daily basis. However, when positive and negative inventory shocks are distinguished, both positive and negative shocks share a statistically significant relationship with natural gas return volatility on the day of the EIA storage announcement. Finally, we newly document the presence of asymmetric effects on conditional variance of natural gas returns following the day the news is released.

The paper proceeds as follows. Section 2 presents the data and discusses inventory information shocks. Section 3 defines the econometric methodology and discusses the estimation results and robustness checks of our findings. Section 4 concludes.

## 2 Data

We proceed by outlining the data for energy commodity prices, namely WTI crude oil and natural gas, and then for EIA inventory announcements and their associated surprises.

We use daily closing prices for the crude oil (WTI) and natural gas (Henry Hub), and covers the period from November 09, 2010 to September 24, 2013. Note that the most commonly traded commodity is the crude oil. Furthermore, the WTI futures contract is viewed as "the world's most liquid forum for crude oil trading, as well as the world's largest-volume futures contract trading" (Dorsey et al., 2007). The Henry Hub, located in Erath, Louisiana, serves as the delivery point in natural gas futures contracts traded at the New York Mercantile Exchange (NYMEX). Given its price transparency and robust liquidity, the Henry Hub futures contract is one of the most traded contracts in the world. These prices are transformed into returns by taking the first difference of the natural log.

Table 1 presents the descriptive statistics for the daily WTI crude oil and natural gas futures returns. The average values vary widely across two series. For example, we show that the highest average is for WTI crude oil (0.041); the lowest average is for natural gas (0.011). Regarding the standard deviation values, the lowest average is 1.756 for oil returns and the highest average is 2.595 for the natural gas returns.

**Table 1** Descriptive statistics for daily returns of crude oil (WTI) and natural gas futures prices (daily return (%))

| | *Mean* | *Median* | *Max* | *Min* | *Std. dev.* | *Skewness* | *Kurtosis* | *Jarque–Bera normality test* | *Obs.* |
|---|---|---|---|---|---|---|---|---|---|
| Crude oil (WTI) | 0.041 | 0.099 | 9.357 | –8.641 | 1.756 | 0.006 | 6.193 | 307.266 (0.000) | 723 |
| Natural gas | 0.011 | –0.027 | 14.187 | –7.915 | 2.595 | 0.449 | 4.736 | 115.247 (0.000) | 723 |

Note: The table reports descriptive statistics of daily crude oil (WTI) and natural gas futures returns, during the period from November 09, 2010 to September 24, 2013. The *p*-values of the test statistics are reported in parentheses. Null hypothesis of the Jarque–Bera test is the normality of the return series.

The daily percentage changes in natural gas futures returns are found to exhibit a values of skewness different to 0 (namely for natural gas) which imply that the distribution is asymmetrical right in a given time period. Regarding the value of the kurtosis for both return series, it is shown to be higher than three, the value for the normal distribution. Also, normality of return series is rejected based on the Jarque–Bera test. In sum, these levels indicate departure from a normal distribution and give good reason to think that the daily price returns can be effectively modelled as a GARCH process.

Data for inventory information are obtained from the EIA report called "Weekly Petroleum Status Report". The EIA report about inventory levels of crude oil is publicly released on Wednesdays at 10:30 AM (US Eastern Time, ET), or on Thursdays at 11:00 AM ET due to holidays. It provides inventory levels of these energy commodities as of the previous Friday. Regarding the natural gas inventory, the EIA releases its weekly report on Thursday morning at 10:30 AM ET. When Thursday is a holiday, the survey is usually released with delay by one day. Moreover, the energy commodity futures contracts used in this current paper are traded at the NYMEX from 9:00 AM to 14:30 ET in the open outcry. Typically, their associated prices respond to the inventory announcements on the event day.

Consensus forecasts of the inventories in the weekly EIA report are obtained from Reuters's survey of analysts published on Monday or Tuesday in news form. Reuters conducts a weekly survey about the expectations of energy commodities based on forecasts by many energy market investors, analysts, and economists. Reuters' inventory survey is computed as the median value of these forecasts and is generally realised around 14:00 ET.

To construct a measure of inventory information surprises, we rely on the Anderson et al. (2003)'s methodology; i.e., we used the difference between realisations and expectations of inventory changes. The first component of the unexpected changes is obtained from inventory changes announced in the EIA reports. The problem is with the second component, i.e., expected inventory changes. Before considering that Reuters analyst' survey can be used as a measure of expected inventory changes, we perform forecast unbiasedness tests using the following model (Andersen et al., 2003; Hui, 2014):

$$\Delta Inv_{EIA,m,w} = \alpha_0 + \alpha_1 \Delta Inv_{\text{Reuters},m,w} + \alpha_2 \Delta P_w^{EIA-\text{Reuters}} + \varepsilon_{EIA,m,w} \quad (1)$$

where

$\Delta\, Inv_{EIA,m,w}$ represents the inventory change in EIA report in week *w* for commodity *m*

$\delta_0$ is a constant,

$\Delta\, Inv_{Reuters,m,w}$ denotes the inventory change in Reuters' survey released in week *w* for commodity *m*,

$\Delta\, P_w^{EIA-Reuters}$ is the change in commodity price between the time of Reuters' survey and EIA report announcements. It represents the change in prices between the day before the release of the EIA report and the day before the Reuters' survey, usually Tuesday and Monday, respectively.

$\varepsilon_{EIA,m,w}$ is the residual terms.

If the survey data are unbiased predictor of the actual change, then we should observe that the estimate of $\alpha_0$ should be insignificant and $\alpha_1$ should be one. Further, if analysts' expectations are revised between the two releases (after the Reuters' survey but before the announcement of the EIA report), then $\alpha_2$ is not statistically different from zero. Table 2 reports the results of equation (1), estimated both with and without the variable $\Delta\, P$.

**Table 2** Unbiasedness tests of Reuters' forecasts for crude oil and natural gas inventory announcements

| | *Crude oil* | | *Natural gas* | |
|---|---|---|---|---|
| $\alpha_0$ | –0.291<br>(0.283) | –0.278<br>(0.306) | –0.895<br>(0.221) | –0.895<br>(0.222) |
| $\alpha_1$ | 1.211***<br>(0.000) | 1.191***<br>(0.000) | 1.027***<br>(0.000) | 1.027***<br>(0.000) |
| $\alpha_2$ | | –0.153<br>(0.360) | | 0.001<br>(0.997) |
| Test of<br>$\alpha_0 = 0$ and $\alpha_1 = 1$ | 2.653<br>(0.265) | 2.222<br>(0.329) | 13.115***<br>(0.001) | 12.977***<br>(0.002) |
| Test of $\alpha_1 = 1$ | 1.754<br>(0.185) | 1.402<br>(0.236) | 11.379***<br>(0.000) | 11.262***<br>(0.000) |
| Obs. | 150 | 150 | 150 | 150 |
| Adj-$R^2$ | 0.273 | 0.274 | 0.990 | 0.990 |

Note: To test whether the Reuters analysts' consensus forecast represents an unbiased estimation of the EIA inventory announcement, we regress equation (1) with and without the change in commodity *m* futures price between the releases of Reuters' survey and EIA report. The sample period of our study is November 09, 2010 to September 24, 2013, which includes 150 EIA inventory news releases for each commodity. The superscript *** indicates statistical significance at the 1% level. *p*-values – are shown in parentheses.

As can be seen in Columns (1)–(2) of Table 2, the joint null hypothesis that $\alpha_0 = 0$ and $\alpha_1 = 1$ cannot be rejected for the crude oil. In particular, the Wald statistic of coefficient test of the null hypothesis is 2.222, with a *p*-value of 0.329 when we include the price change variable. Consequently, the Reuters' consensus survey expectations of the crude oil inventory is an unbiased forecast inventory changes listed in EIA reports. There is no evidence of a significant impact of the price change, indicating that there were no forecast revisions between the two releases.

However, regarding the natural gas, it is seen that the Wald Chi-squared test rejects the null hypothesis that $\alpha_0 = 0$ and $\alpha_1 = 1$.[3] Note that the slope coefficient (1.027) indicates that the average forecast underestimates the actual inventory change by about 2%. This value do however shows that the consensus survey expectations predicted changes explain 98.7% of the variation in the actual changes, indicating that the predictive content of the Reuters forecast is important (see also Chiou-Wei et al., 2014). In addition, our sample does not contain observations where the natural gas inventory surprises are exactly zero. The average values of the standardised surprise component for inventory announcement are close to zero. Based upon these results and the other statistics of the standardised surprise (see analysis below), the Reuters survey can be assumed to reflect market expectations.[4] It appears that the analysts do not systematically overforecast or underforecast inventories.

Reuters' survey results are shown to be unbiased predictor of the actual change in inventory as released by EIA. Then, we define inventory information shock as the difference between actual change of inventory and the expected change of inventory released by Reuters.

Thus, inventory surprise contained in EIA reports in our study, $S_{EIA,m,w}$, is given by:

$$S_{EIA,m,w} = \Delta Inv_{EIA,m,w} - \Delta Inv_{\text{Re}uters,m,w} \tag{2}$$

To come up with a common metric of "surprise" for oil and gas, we follow Miao et al. (2018) and consider the standardised surprise component of the inventory that EIA announces, the $SSI_{EIA,m,w}$, which is defined as the surprise component standardised by its unconditional standard deviation.[5] Thus, the standardised surprise contained in EIA reports in our study, is given by:

$$SSI_{EIA,m,w} = S_{EIA,m,w} / \sigma \tag{3}$$

Finally, Table 3 provides summary statistics of the inventory surprise and the standardised surprise contained in EIA reports for crude oil and natural gas as computed in equations (2) and (3). For each commodity, we present statistics for the overall sample (all shocks) which is further divided into positive and negative surprises subsamples. Our sample period spans from November 09, 2010 to September 24, 2013, resulting in 150 EIA inventory news releases for each commodity. The proportions of positive and negative surprises used in this study are approximately the same. We think that this sample is sufficient to carry out a statistical analysis of surprises.

**Table 3** Summary statistics of inventory shocks

| | *Mean* | *Median* | *Max* | *Min* | *Std. dev.* | *Skewness* | *Kurtosis* | *Obs.* |
|---|---|---|---|---|---|---|---|---|
| *Panel A : oil inventory shock* | | | | | | | | |
| All shocks | –0.255 | 0.028 | 7.534 | –10.201 | 3.307 | –0.357 | 3.023 | 150 |
| Std. surp. | –0.077 | 0.008 | 2.277 | –3.083 | 1.000 | –0.357 | 3.023 | 150 |
| Negative shocks | –2.824 | –2.200 | –0.044 | –10.201 | 2.344 | –0.944 | 3.257 | 75 |
| Std. surp. | –1.204 | –0.938 | –0.018 | –4.351 | 1.000 | –0.9441 | 3.257 | 75 |
| Positive shocks | 2.313 | 1.900 | 7.534 | 0.100 | 1.777 | 0.743 | 2.961 | 75 |
| Std. surp. | 1.301 | 1.068 | 4.237 | 0.056 | 1.000 | 0.743 | 2.961 | 75 |
| *Panel A : Natural gas inventory surprises* | | | | | | | | |
| All shocks | –0.960 | 0.000 | 35.000 | –53.000 | 9.227 | –0.846 | 9.741 | 150 |
| Std. surp. | –0.104 | 0.000 | 3.792 | –5.743 | 1.000 | –0.846 | 9.741 | 150 |
| Negative shocks | –7.849 | –6.000 | –1.000 | –53.000 | 7.133 | –3.683 | 23.158 | 73 |
| Std. surp. | –1.100 | –0.841 | –0.140 | –7.430 | 1.000 | –3.683 | 23.158 | 73 |
| Positive shocks | 6.308 | 5.000 | 35.000 | 1.000 | 5.406 | 2.619 | 13.185 | 68 |
| Std. surp. | 1.166 | 0.924 | 6.473 | 0.184 | 1.000 | 2.619 | 13.185 | 68 |

Overall, on average, crude oil inventory surprises are smaller in magnitude compared to those related to natural gas. As for the crude oil, the highest standardised surprise regarding the overall sample is –3.083 and the lowest is 2.277, and the mean is −0.077. For the negative shocks, the average is –1.204; whereas, the mean for the positive shock subsample is 1.301. As for natural gas, the average of the standardised surprise for the overall sample is –0.104. However, when positive and negative inventory shocks are distinguished, the averages values are –1.100 and 1.166, respectively.

Having derived the source of expectations on inventory changes in the EIA weekly reports, we now proceed to construct a model to examine the reaction of energy commodity prices in return and volatility to inventory surprise.

## 3 The response of energy commodity markets to inventory surprises

In the current section, we investigate the impact of unexpected changes in inventory on the volatility and returns of energy futures prices. As mentioned above, the descriptive statistics of the crude oil and natural gas return series highlight a possible departure from a normal distribution and give good reason to think that the daily return series can be effectively modelled as a GARCH process.

### *3.1 The econometric methodology*

To formally examine the effect of inventory information shocks inherent in the EIA report on commodity futures markets, we use the Generalised Autoregressive Conditional Heteroskedasticity (GARCH) family of statistical processes (Bollerslev, 1986; Engle, 1982) to jointly model the conditional mean and variance of price returns.

Specifically, we apply an EGARCH model, proposed by Nelson (1991), which is a good choice for our application because such a model ensures the conditional variance is strictly positive. Also, it seems to be well suited to explain volatility asymmetry and allows negative volatility coefficients.

The mean equation for each commodity $m$ is specified as:

$$R_{m,t} = \delta_0 + \delta_1 R_{m,t-1} + \delta_2 USDI_t + \lambda_1^0 SSI_{EIA,m,w} + \varepsilon_t \tag{4}$$

In the conditional mean specification given on equation (4), we consider that the commodity futures price return is affected mainly by the unexpected inventory changes in EIA reports. In addition, we introduce to the model a control variable, the exchange rate of the US dollar, widely used in empirical works.

An EGARCH (1, 1) specification can be written, in terms of the conditional variance of returns, as:

$$In\left(\sigma_t^2\right) = \omega + \gamma In\left(\sigma_{t-1}^2\right) + \alpha \left|\frac{\varepsilon_{t-1}}{\sigma_{t-1}}\right| + \beta \frac{\varepsilon_{t-1}}{\sigma_{t-1}} + \lambda_2^0 SSI_{EIA,m,w} \tag{5}$$

where

$m$ = {crude oil, natural gas};

$w = 1,\ 2, \ldots,\ 150$ (weeks);

$\delta_0$ is the intercept term;

$R_{m,t}$ is the daily commodity return which is the percentage change in commodity prices;

$R_{m,t-1}$ is the lagged value of the daily return;

$SSI_{EIA,m,w}$ is the standardised surprise of crude oil inventory on day $t$ for $m$ = {crude oil, natural gas} and $w = 1,\ 2, \ldots,\ W$ (weeks). The set of surprises enters in the form of dummy variables that take the value of the surprise for the days when an announcement is made and zero otherwise.

$\varepsilon_t$ is the residual terms.

Equation (2) defines the variance as an exponential GARCH (1, 1) process. We introduce the variance equation in the model to capture the conditional heteroscedasticity for the retained series. Also, the conditional variance is expressed as a linear function of previous squared errors and conditional variances.

$\sigma_t^2$ and $\sigma_{t-1}^2$ denotes the conditional variance of commodity returns respectively at time $t$ and $t$-1 which depends upon the mean volatility level ($\omega$),

$\gamma$ measures the volatility persistence for a given shock in the conditional variance,

$\beta$ specified the presence of the asymmetric leverage effect.

$\lambda_2^0$ measures the impact of inventory surprises on the variability of daily commodity returns on the day the EIA releases its inventory reports.

If $\lambda_1^0$ is not different from zero, we would conclude that the surprise has no influence on daily commodity returns. Finally, we test the hypothesis that the variance of commodity returns is influenced by the surprise through an analysis of $\lambda_2^0$.

Next, we will not be limited with only the effect of inventory shocks in the EIA report on announcement day but also the effect on the days following the report. We then incorporate such information into the mean and variance equations. We follow Hui (2014) and assume that the value of an inventory shock remains the same from the time of this announcement until the next announcement. More specifically, the day the EIA releases the inventory report, the value of the inventory shocks for the week becomes the new value, and it remains unchanged until the next EIA report. It is interesting to note that we retain the similar exercise for the volatility analysis.

We use the following extended mean and variance equations incorporated with the two inventory surprise variables:

$$R_{m,t} = \delta_0 + \delta_1 R_{m,t-1} + \delta_2 USDI_t + \lambda_1^0 SSI_{EIA,m,w} + \lambda_1^1 SSI_{EIA,m,w} + \varepsilon_t \tag{6}$$

$$In\left(\sigma_t^2\right) = \omega + \gamma In\left(\sigma_{t-1}^2\right) + \alpha\left|\frac{\varepsilon_{t-1}}{\sigma_{t-1}}\right| + \beta\frac{\varepsilon_{t-1}}{\sigma_{t-1}} + \lambda_2^0 SSI_{EIA,m,w} + \lambda_2^1 SSI_{EIA,m,w} \tag{7}$$

The coefficients $\lambda_1^0\left(\lambda_2^0\right)$ indicate the effect of inventory surprises on the day of the EIA report, while the coefficients $\lambda_1^1\left(\lambda_2^1\right)$ present the effect on the days following the report.

As a control variable that drives changes in commodity prices we used the USDI which is daily changes of the value of the US dollar relative to a basket of foreign currencies. Note that the daily changes in the US dollar index exhibit an average of 0.005%. The standard deviation, Max and Min values are respectively 0.397, 1.420 and –1.460.

As crude oil contracts are sold in US dollars, the fluctuations in the exchange rates should affect the price of crude oil. Many studies highlight the important role of the US exchange rate in determining crude oil prices (Sadorsky, 2000; Yousefi and Wirjanto, 2004; Zhang et al., 2008; Akram, 2009; Hui, 2014). Moreover, more recent evidence shows that the two markets are negatively associated (Wu et al., 2012; Reboredo et al., 2014).

Note that natural gas prices and the US Dollar Index are known to be moved in opposite directions. When the dollar falls in value against other currencies, gas prices rise. A great part of the price of gas depends on oil prices. All oil contracts are sold in US dollars.

Having introduced the model specification, in the next section, we quantify the effects of the inventory surprises on the volatility and return of energy futures prices.

## *3.2 Results and discussion*

In this section, we investigate using the model specified in Sub-section 3.2 above, the behaviour of energy commodity futures return and volatility on response to the surprise component of the EIA weekly inventory report announcements. For each commodity, in the total sample of 150 inventories observed during the period from November 09, 2010 to September 24, 2013, the proportions of positive and negative shocks in the sample are approximately the same.

We have defined the inventory surprise as the difference between the actual inventory change released in the EIA reports and the expected change of inventory (i.e., Reuters survey median). Measuring shocks this way means that a positive shock occurs when the Reuters's survey of analysts under-forecast inventory in the weekly storage report. A negative shock, occurs when the analysts over-forecast inventories. We follow Miao et al. (2018) and divide this difference by its unconditional standard deviation to obtain standardised inventory surprise.

In Column (1) of the Table 4, we report the empirical results for the crude oil price returns and the associated conditional volatility as given in equations (4) and (5). We show that the impact of inventory surprise $\left(\text{as measured by } \lambda_1^0\right)$, observed only on the day the EIA releases its inventory reports, on returns is negative and statistically significant. In particular, an announcement that leads to a decrease in the inventory surprise, on average, induces an increase in the oil prices. This result is in line with the theory that indicates that lower (higher) inventory than expected, leads futures returns to increase (decrease). The pattern is then similar to that in Hui (2014), who also find that inventory shocks negatively impact the returns. On report release days, the surprise leads to an average fall in returns of 0.302%, which is to be largely superior compared with the 0.00069 in Hui (2014).

**Table 4** Estimated parameters of the effects of inventory surprises on daily crude oil returns and volatility

| | *(1)* | *(2)* | *(3)* | *(4)* |
|---|---|---|---|---|
| Conditional Mean | | | | |
| $\delta_0$ | 0.041 (0.435) | 0.039 (0.462) | 0.059 (0.292) | 0.085 (0.309) |
| $\delta_1$ | –0.021 (0.583) | –0.024 (0.547) | –0.020 (0.597) | –0.023 (0.565) |
| $\delta_2$ | –1.439*** (0.000) | –1.419*** (0.000) | –1.422*** (0.000) | –1.419*** (0.000) |
| $\lambda_1^0$ | –0.302*** (0.009) | –0.306*** (0.008) | | |
| $\lambda_1^1$ | | 0.734 (0.220) | | |
| $\lambda_1^{0NEG}$ | | | –0.138 (0.176) | –0.123 (0.263) |
| $\lambda_1^{0POS}$ | | | –0.235** (0.022) | –0.242** (0.033) |
| $\lambda_1^{1NEG}$ | | | | –0.027 (0.766) |
| $\lambda_1^{1POS}$ | | | | –0.079 (0.278) |
| Conditional variance | | | | |
| $\omega$ | –0.120** (0.033) | –0.121** (0.038) | –0.125** (0.025) | –0.104* (0.094) |
| $\alpha_i$ | 0.499*** (0.000) | 0.502*** (0.000) | 0.499*** (0.000) | 0.501*** (0.000) |
| $\beta_i$ | –0.090** (0.034) | –0.100** (0.021) | –0.091** (0.034) | –0.101** (0.020) |
| $\gamma$ | 0.696*** (0.000) | 0.693*** (0. 000) | 0.702*** (0. 000) | 0.708*** (0. 000) |

**Table 4** Estimated parameters of the effects of inventory surprises on daily crude oil returns and volatility (continued)

| | *(1)* | *(2)* | *(3)* | *(4)* |
|---|---|---|---|---|
| $\lambda_2^0$ | 0.063 (0.503) | 0.076 (0.473) | | |
| $\lambda_2^1$ | | –0.019 (0.626) | | |
| $\lambda_2^{0NEG}$ | | | 0.055 (0.549) | 0.052 (0.624) |
| $\lambda_2^{0POS}$ | | | 0.036 (0.684) | 0.074 (0.479) |
| $\lambda_2^{1NEG}$ | | | | 0.029 (0.636) |
| $\lambda_2^{1POS}$ | | | | –0.066 (0.207) |

Note: This table reports estimated coefficients from E-GARCH model given by equations (4) and (5). We used daily series for oil price returns, from November 09, 2010 to September 24, 2013. The sample period includes 150 inventory announcements as released by EIA. The inventory surprise measured only on event day is the actual inventory change released minus consensus average forecast as reported by Reuters. The proportions of positive and negative shocks in the sample are approximately the same. The superscripts ***, **, and * indicate statistical significance at the 1%, 5% and 10% level, respectively. *p*-values – are shown in parentheses.

As an additional test, we introduce the inventory surprises both on the announcement day and the following day until the next EIA report. In Column (2) of Table 4, we present the coefficient estimates of the effects both on the EIA announcement day and on the following day based on equation (6). The findings indicate that the all shock coefficients are statistically significant and negative during the EIA announcement day confirming the significant effect shown in Column (1), while the effect after the announcement day is insignificant $\left(\text{as measured by } \lambda_1^1\right)$. It is perhaps surprising, the unexpected inventory changes on the following days do not play a significant role in explaining oil price returns, supporting the findings of Hui (2014). One possible explanation for this may relate to the fact that the method is not adequate for analysing how the market absorbs the inventory surprises after the EIA announcement day. Another reason is that the reaction of crude oil market to inventory announcement disappears shortly.

The point of this paper is not to show only the reactions of energy commodity prices to the inventory information shocks, but it is nevertheless interesting to see whether the content of news discriminated between "negative" and "positive" news impact these prices.

We report our attempt at testing the possible existence of the asymmetric response of price returns and volatility to unexpected inventory changes, by using the following extended mean and variance equations

$$R_{m,t} = \delta_0 + \delta_1 R_{m,t-1} + \delta_2 USDI_t + \lambda_1^{0Neg} SSI_{EIA,m,w} + \lambda_1^{0Pos} SSI_{EIA,m,w} + \varepsilon_t \tag{8}$$

$$\begin{aligned} R_{m,t} = {} & \delta_0 + \delta_1 R_{m,t-1} + \delta_2 USDI_t + \lambda_1^{0Neg} SSI_{EIA,m,w} + \lambda_1^{0Pos} SSI_{EIA,m,w} \\ & + \lambda_1^{1Neg} SSI_{EIA,m,w} + \lambda_1^{1Pos} SSI_{EIA,m,w} + \varepsilon_t \end{aligned} \tag{9}$$

$$In\left(\sigma_t^2\right)=\omega+\gamma In\left(\sigma_{t-1}^2\right)+\alpha\left|\frac{\varepsilon_{t-1}}{\sigma_{t-1}}\right|+\beta\frac{\varepsilon_{t-1}}{\sigma_{t-1}} \\ +\lambda_2^{0Neg}SSI_{EIA,m,w}+\lambda_2^{0Pos}SSI_{EIA,m,w} \tag{10}$$

$$In\left(\sigma_t^2\right)=\omega+\gamma In\left(\sigma_{t-1}^2\right)+\alpha\left|\frac{\varepsilon_{t-1}}{\sigma_{t-1}}\right|+\beta\frac{\varepsilon_{t-1}}{\sigma_{t-1}}+\lambda_2^{0Neg}SSI_{EIA,m,w} \\ +\lambda_2^{0Pos}SSI_{EIA,m,w}+\lambda_2^{1Neg}SSI_{EIA,m,w}+\lambda_2^{1Pos}SSI_{EIA,m,w} \tag{11}$$

In this model, $\lambda_j^{tNeg}$ and $\lambda_j^{tPos}$ ($t$ = 0, 1; $j$ = 1, 2) are the coefficients that were checked to examine the asymmetric impact of the unexpected inventory changes for $m$ = {crude oil, natural gas}, on returns and conditional volatility.

In contrast to Hui (2014), we find that inventory announcements are most important when they contain positive news for oil returns during our sample study. Specifically, a positive surprise indicates that commodity in storage is higher than expected and conversely for a negative shock. From the results in Column (3) of Table 4, we find that, on the day of the EIA storage announcement, the positive shock has a significant negative effect $\left(\text{coefficient } \lambda_1^{0POS}\right)$ on crude oil returns, while EIA negative shock is insignificant $\left(\text{coefficient } \lambda_1^{0NEG}\right)$. It seems that the effects of negative or positive information shocks are not symmetric. For instance, a 1% positive crude oil inventory shock in EIA reports will result in a total of 0.235% drop in the futures returns in the day of the EIA news release. However, in Column (4) we show that the effects of both positive and negative crude oil inventory shocks, as measured respectively by the coefficients $\lambda_1^{1POS}$ and $\lambda_1^{1NEG}$, following the announcement day are insignificant.

Regarding the variance equation as given on Panel B of Table 4, it is shown that there is no evidence of effect of inventory surprises on oil price volatility $\left(\text{coefficient } \lambda_2^{0}\right)$. We confirm results from Hui (201) showing no announcement day effects on conditional variance of daily crude oil returns. Our findings are also in line with those of Ye and Karali (2016), who find that the response of volatility to unexpected inventory changes absorbed within an hour in a trading day study. Wolfe and Rosenman (2014) find that oil volatility remains higher than usual for roughly one hour after the inventory announcements. Consequently, one can argue that no impact can be found on a daily basis. In addition, we find that the estimated EGARCH parameters to be significant. For example, the asymmetric component and the lagged conditional variance term are highly significant at the 1% level.

As for the control variable, we find that, in all specifications, i.e. Columns (1)–(4), the daily changes in US dollar index have a negative and significant impact on oil prices. Depreciation of the US dollar can push crude oil prices up and appreciation of the US dollar can push crude oil prices down. In particular, a 1% increase in US dollar index is associated with a – 1.4 % crude oil price decrease on the day of the news release. This finding is consistent with an early paper by Sadorsky (2000) and a more recent paper Hui (2014).

Table 5 reports the EGARCH results for the influence of the inventory shock contained in EIA reports on natural gas prices. Overall, we find similar findings as for the crude oil, namely on the return level. First, for the overall sample, the impact of shock is statistically significant and negative on the day of the report releases. An inventory shock, which is negative on average, associated with an increase in the natural gas price return. For instance, a 1% changes in the surprise leads to a rise of roughly 0.866% in the futures returns in the day of the EIA news release. Second, we find insignificant estimates corresponding to the interval of the following days suggesting that there is no evidence of post-report effects for the EIA reports. These results are consistent with those by Chiou-Wei et al. (2014) based on the average predicted change reported by Bloomberg.

**Table 5** Estimated parameters of the effects of inventory surprises on daily natural gas returns and volatility

| | *(1)* | *(2)* | *(3)* | *(4)* |
|---|---|---|---|---|
| Conditional Mean | | | | |
| $\delta_0$ | –0.019 (0.836) | –0.023 (0.804) | 0.057 (0.572) | 0.057 (0.674) |
| $\delta_1$ | –0.060 (0.164) | –0.057 (0.185) | –0.066 (0.055)* | –0.060* (0.081) |
| $\delta_2$ | –0.420* (0.060) | –0.433* (0.051) | –0.172 (0.508) | –0.221 (0.381) |
| $\lambda_1^0$ | –0.866*** (0.000) | –0.975*** (0.000) | | |
| $\lambda_1^1$ | | 0.090 (0.453) | | |
| $\lambda_1^{0NEG}$ | | | –0.554 (0.102) | –0.061 (0.149) |
| $\lambda_1^{0POS}$ | | | –0.948*** (0.001) | –0.153*** (0.001) |
| $\lambda_1^{1NEG}$ | | | | 0.009 (0.531) |
| $\lambda_1^{1POS}$ | | | | 0.011 (0.390) |
| Conditional Variance | | | | |
| $\omega$ | –0.052** (0.028) | –0.051** (0.016) | 2.923*** (0.000) | 3.194*** (0.000) |
| $\alpha_i$ | 0.099*** (0.005) | 0.091*** (0.005) | –0.085 (0.173) | –0.098 (0.131) |
| $\beta_i$ | –0.022 (0.165) | –0.024* (0.094) | –0.033 (0.334) | –0.033 (0.365) |
| $\gamma$ | 0.985*** (0.000) | 0.988*** (0. 000) | –0.573*** (0.001) | –0.625*** (0. 000) |
| $\lambda_2^0$ | –0.025 (0.491) | –0.060 (0.160) | | |
| $\lambda_2^1$ | | 0.014 (0.176) | | |
| $\lambda_2^{0NEG}$ | | | –0.313*** (0.001) | –0.028 (0.107) |

**Table 5** Estimated parameters of the effects of inventory surprises on daily natural gas returns and volatility (continued)

| | *(1)* | *(2)* | *(3)* | *(4)* |
|---|---|---|---|---|
| $\lambda_2^{0POS}$ | | | 0.234* (0.058) | 0.021 (0.336) |
| $\lambda_2^{1NEG}$ | | | | 0.015 (0.287) |
| $\lambda_2^{1POS}$ | | | | –0.042** (0.024) |

Note: This table reports estimated coefficients from E-GARCH model given by equations (4) and (5). We used daily series for natural gas price returns, from November 09, 2010 to September 24, 2013. The sample period includes 150 inventory announcements as released by EIA. The inventory surprise measured only on event day is the actual inventory change released minus consensus average forecast as reported by Reuters. The proportions of positive and negative shocks in the sample are approximately the same. The superscripts ***, **, and * indicate statistical significance at the 1%, 5% and 10% level, respectively. *p*-values – are shown in parentheses.

We find no evidence of an economically meaningful reaction of volatility to the inventory surprise on (or following) the day the EIA news is released. Our findings are consistent with those documented by Linn and Zhu (2004), indicating that that the response of volatility to inventory report announcement disappears shortly and that no effect can be found on a daily basis. Wolfe and Rosenman (2014) confirm the fast adjustment of gas volatility, which remains higher than usual for about 30 min after the inventory announcements.

There are clear and asymmetric responses in natural gas returns to positive and negative inventory surprises. Positive shock from the EIA reports consistently decreases returns as evidenced by the negative coefficient $\lambda_1^{0POS}$ in the day of the EIA news release. The identified relationship is more strongly when considering only the surprise on the announcement day. On the other hand, the effect of negative shock which is determined by the parameter $\lambda_1^{0NEG}$ is insignificant. However, in Column (4) we show that the effects of both positive and negative crude oil inventory shocks following the announcement day are insignificant.

Surprisingly, a further finding of the research is that both positive and negative inventory shocks (coefficient $\lambda_2^{0NEG}$ and $\lambda_2^{0POS}$) exhibit statistically significant relationship with no asymmetric impact on conditional variance of daily returns on the day of the EIA storage announcement. It is important to note that for negative surprises, one must bear in mind that the associated negative coefficient indicates that the conditional variance of daily returns increases in response to the negative surprise in the announcement. In addition, we find that volatility significantly rises with positive inventory surprises. The magnitude of estimated coefficients is higher for negative surprises, indicating they have a stronger impact. These results are consistent with prior literature which attributes the increase in volatility in asset returns to information flow (for instance, Ross, 1989).

Moreover, on the days following the EIA announcements, the positive surprise coefficient $\lambda_2^{1POS}$ has a negative sign and is statistically significant. This result means that decreased volatility is occurred on the following day the news is released with positive surprises. We find no evidence of an economically meaningful impact of negative surprise on natural gas return volatility.

Taken together, the evidence suggests that natural gas volatility at daily frequency is related to inventory surprises. In contrast to us, Linn and Zhu (2004) find that natural gas futures prices experience systematically larger volatility only at the time of the storage news announcement in a study with high frequency, i.e. over 5-min intervals. The empirical evidence suggests also that market participants decrease their trading activity on the days following the report and increase their trading activity once the EIA reports are released.

Finally, the above findings lend empirical support to the hypothesis that inventory information surprises are likely to be an important determinant of energy commodity prices. In fact, with a one-day window, our results also contribute to the growing literature on asymmetrical responses of energy market prices to inventory news. We document also that the response of these markets depends crucially on the size of the study window through which announcements may affect return. Finally, we find novel evidence of the heterogeneity in the responsiveness of futures price volatility to inventory surprises.

## 4 Conclusions

This study focuses on the effects of the inventory shocks on the returns and the volatility of energy commodity markets using EGARCH model. We use daily data for futures prices during a sample period that starts on November 09, 2010 and ends on September 24, 2013. The sample period includes 150 EIA inventory news releases for each commodity. To obtain inventory surprises we used the difference between actual change of inventory announced in the EIA's weekly reports and the forecast value of the Reuters' survey right around the announcement time.

Empirical results indicate inverse effects of the unexpected inventory changes in EIA report on commodity price returns on the day of the EIA announcement. In particular, we find that an inventory announcement that results in decrease of unanticipated component of inventory changes, on average, leads to a rise of commodity futures returns. Furthermore, the reaction of commodity prices to the inventory change surprise following the day the news is released becomes insignificant. A further finding of the research is that when positive and negative inventory surprises are distinguished, we find that asymmetric responses in futures returns to EIA inventory are pronounced. More specifically, we find that positive surprise has a significant negative effect on returns, while negative surprise is insignificant.

With respect to conditional variance of daily oil returns, we show that there is no significant impact of inventory surprises on the variance, no matter what the proxy variable is which supports the findings of Hui (2014). However, unlike in the case of oil price volatility, the empirical evidence also suggests that natural gas return volatility is susceptible to both positive and negative surprises in the EIA announcement days. Whereas only positive surprises on the following days matter for return volatility.

The findings are expected to entail important practical and policy making implications for several reasons. For policy makers, the link between inventory information and energy futures markets need to be taken into account. Moreover, the results provide useful insights for producers and consumers of energy whose prices are being affected by unexpected inventory levels. The findings are also useful for dynamic portfolio choice, as part of the fluctuations in the commodity futures prices corresponds to the variation in the surprises. Understanding the dynamics of energy volatility and their major determinants, namely inventory announcements, can be beneficial for traders in their arbitrage opportunities given that volatility is a key in pricing of derivatives (Lee and Zyren, 2007).

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## Notes

1 This argument is also consistent with what has been found in other financial markets, for instance, the effect of the surprise component of monetary policy on stock prices (Bernanke and Kuttner, 2005). Kuttner (2001) finds a similar results for the US bond market.

2 Wolfe and Rosenman (2014) study the effect of inventory surprises only on volatility.

3 The *F*-test statistic also rejects the null hypothesis.

4 Wolfe and Rosenman (2014) and more recently Miao et al. (2018) used the same analysis. The mean values of the gas inventory surprises as reported by Wolfe and Rosenman (2014) is 0.05.

5 Halova et al. (2014) proposed another methodology for standardising announcement units by dividing the difference between the actual and the expected changes of inventory by the inventory levels.