The time-varying spillover effect between WTI crude oil futures returns and hedge funds

Yue-Jun Zhang\textsuperscript{a,b,}\textsuperscript{*}, Yao-Bin Wu\textsuperscript{c}

\textsuperscript{a}Business School, Hunan University, Changsha, 410082, China
\textsuperscript{b}Center for Resource and Environmental Management, Hunan University, Changsha, 410082, China
\textsuperscript{c}School of Management, Fudan University, Shanghai, 200433, China

\section*{ARTICLE INFO}

\textbf{JEL classification:}
Q01
G15
O16

\textbf{Keywords:}
Crude oil futures
DCOT reports
Hedge funds
Time-varying granger causality

\section*{ABSTRACT}

To capture the relationship change between WTI crude oil returns and hedge funds in recent years, the linear and nonlinear Granger causality test approaches and Hong's time-varying information spillover statistics are employed based on the data from 2006 to 2017. The empirical results indicate that, first, hedge funds' net positions may Granger cause crude oil futures returns in the linear manner but the nonlinear relationship appears weaker. Second, both in the linear and nonlinear manners, the influence of crude oil futures prices has been evidently strengthened when they experience high volatility whilst the influence of hedge funds' net positions appears stronger only when crude oil futures prices rise substantially. Finally, hedge funds play an important role in pushing up crude oil price bubbles which are responsible for the crash of crude oil prices in 2008, but the crash of oil prices in 2014 is more attributed to market fundamentals.

\section*{1. Introduction}

In the past two decades, the pace of commodity financialization has been constantly accelerated (Zhang, Chevallier, & Guesmi, 2017). The development of technology and the need for investment have made financial products based on commodities a good diversification tool for investors (Gkanoutas-Leventis & Nesvetailova, 2015). Meanwhile, the regulation has become more permissive since the launch of the Commodities Future Modernization Act (CFMA) in 2000. As a result, institutional investors have built their positions rapidly in the commodity futures markets since 2004 (Basak & Pavlova, 2016), and a large number of institutional investors have held commodities through commodity index futures. In fact, financialization provides more opportunities to spread risks during the periods of economic ascent but also multiplies the systematic risks during the descent (Gkanoutas-Leventis & Nesvetailova, 2015; Yu, Du, Fang, & Yan, 2018).

The last decade has witnessed striking volatility in commodities prices, of which crude oil is undoubtedly one of the most important products. Since 2003, crude oil prices have experienced violent fluctuations. The US West Texas Intermediate (WTI) crude oil spot prices reached the highest at $145 per barrel in July 2008. Meanwhile, hedge funds' share grew rapidly in global crude oil futures market accounting for $260 billion, which was nearly 20 times that in 2003 (Cho, 2008). However, WTI crude oil spot prices fell to $30 per barrel in late 2008 due to the global financial crisis, but after 2009, WTI crude oil prices have experienced a gradual rising trend. However, after the second half of 2014, U.S. shale producers increased production whilst traditional oil producing countries such as Libya and Iraq began to resume production, which resulted in the supply of crude oil significantly exceeding demand (OPEC, 2014).

* Corresponding author. Center for Resource and Environmental Management, Hunan University, Changsha, 410082, China.
E-mail address: zyjmis@126.com (Y.-J. Zhang).

\textsuperscript{*} Corresponding author. Center for Resource and Environmental Management, Hunan University, Changsha, 410082, China.
E-mail address: zyjmis@126.com (Y.-J. Zhang).

https://doi.org/10.1016/j.iref.2019.02.006
Received 18 April 2018; Received in revised form 9 February 2019; Accepted 13 February 2019
Available online 15 February 2019
1059-0560/© 2019 Elsevier Inc. All rights reserved.
Additionally, Volcker Rule faced execution and U.S. dollar experienced continuous appreciation. As a result, WTI crude oil prices dropped sharply and reached a record low price at $26 per barrel after the global financial crisis, in early 2016. With the limit crude oil production of OPEC and Russia, WTI crude oil prices have been on an upward trend afterwards.

As we all know, international crude oil market proves a typical complex system, where it is difficult to capture market changes simply based on the supply and demand situation (Cifarelli & Paladino, 2010; Gallo, Mason, Shapiro, & Fabritius, 2010; Zhang & Wang, 2019; Zhang & Zhang, 2018). According to the statistics of the Commodity Futures Trading Commission (CFTC), the non-commercials held 53% positions of crude oil futures and options in the New York Mercantile Exchange (NYME) by the end of 2016.1 Along with the increasing proportion, financial positions aiming to speculate without physical support have increasing influence on crude oil prices (Li, Kim, & Park, 2016), of which hedge funds constitute the major part (Jing, Kim, & Park, 2014). Therefore, we also have to place much emphasis on the financial positions.

Although there have been many studies on the relationship between crude oil prices and financial positions, most have regarded non-commercial positions as speculators’ positions, which may lead to a misunderstanding of the speculators’ influence on crude oil prices. The judgment of speculators should be based on trading behaviors rather than registration (Kaufmann, 2011). Non-commercials constitute a part of speculators; however, speculative trading activities also exist in commercials (Ederington & Lee, 2002; Irwin & Sanders, 2010). Additionally, existing literature mainly focuses on the period of global financial crisis in 2008 but there is a lack of studies on the sharp fluctuations in crude oil prices observed since 2014. Meanwhile, the main methods used in previous relevant studies have indicated the relationship in the mean and static sense rather than considering the time-varying characteristics, which may ignore the relationship changes over time.

Under these circumstances, this paper focuses on the relationship between crude oil futures returns and hedge funds’ net positions, which are the largest part of the non-commercial positions, and explores its time-varying characteristics over the last decade. Specifically, we first detect the general relationship from June 2006 to December 2017 using the Granger causality test both in linear and nonlinear forms. Then, the linear time-varying characteristics between crude oil futures returns and hedge funds’ net positions are explored using Hong’s time-varying information spillover statistics. The rolling window is also introduced into DP Granger test to investigate their nonlinear time-varying characteristics. Through this study we hope to offer helpful information for investors, analysts and related market regulators.

The main contribution of this paper consists of two aspects. On the one hand, the dynamic interaction between crude oil futures and hedge funds over the past decade is analyzed. On the other hand, the comparison is made for the causes of the crashes of crude oil futures prices in 2008 and 2014 according to the information spillover strength between crude oil futures returns and hedge funds’ net positions.

The remainder of the paper is organized as follows. Section 2 reviews related literature. Section 3 introduces empirical methods and data definitions. Section 4 presents empirical results and analyses, and Section 5 concludes the paper.

2. Literature review

As the main representative of commodities, crude oil has been widely studied by academia. In the 21st century, international crude oil prices began to deviate from the fundamentals and bubbles gradually grew. Lammerding, Trede, and Wilfling (2013) introduce two Markov-regimes into the state-space representation to investigate the bubbles of WTI crude oil prices and find that they have existed significantly since 2005 and reached the maximum in mid-2008. Similarly, Zhang and Yao (2016) find that crude oil prices are significantly driven by bubbles from the end of 2001 to mid-2008, using the state-space model. Zhang and Wang (2015) also claim the existence of significant bubbles in WTI crude oil prices during 2003–2012, and the price dynamics cannot be fully explained by the supply and demand situation.

The existence of crude oil price bubbles implies strong impact of financial investors on crude oil prices over the past decade.2 De Long, Shleifer, Summers, and Waldmann (1990) develop a bubble model to reveal the economic mechanisms by which speculation can affect prices. Using these mechanisms, Tokic (2011) shows that crude oil price bubbles in 2008 were caused by commercial arbitrageurs and speculators jointly. According to the contribution of macro-economic variables and financial speculation to crude oil price fluctuations, Morana (2013) finds that macro-economic shocks have been the main upward driver since mid-1980s whereas the influence of financial shocks began to rise after 2000s, and the crash of crude oil price in 2007-2008 was caused by macro-economy and financial speculation jointly. Using endogenously determined break tests, Fan and Xu (2011) find that speculation and episodic events were the main drivers of crude oil price changes from 2000 to 2004. However, as the influence of speculation appeared more prominent with the inflow of large amounts of speculative funds from 2004 to 2008, the supply and demand became comparatively less important. Besides, Yang, Han, Hong, and Wang (2016) prove that speculative activities have significant explanatory power for the dynamics of oil prices during 2003–2011 with an interval regression model.

In both linear and nonlinear ways, Zhang (2013) states that speculation has a robust linear effect on crude oil prices but weak nonlinearity, and has significant linear shocks on crude oil prices during the periods of high volatility. Besides, Li et al. (2016) use the GNNTS model to examine the nonlinear influence of commercial and non-commercial net long positions on WTI crude oil prices, and

---

1 The data are derived from a weekly report by CFTC, which are available at: http://www.cftc.gov/MarketReports/CommitmentsOfTraders/HistoricalCompressed/index.htm.

conclude that hedgers and speculators both contributed to crude oil price bubbles in 2008 and the effect of them has become stronger since 2011; and speculators tend to extend crude oil price fluctuations but hedgers do not.

It should be noted that the above studies have not only identified non-commercial positions as speculators’ positions. This classification is simple and non-detailed. In fact, non-commercials do not cover all the speculators and commercials also conduct some speculative trading activities (Ederington & Lee, 2002; Irwin & Sanders, 2010). Meanwhile, non-commercials contain different types of traders whose relationships with crude oil prices are also different. By examining the Granger-causality between the prices of WTI crude oil futures and different types of net position changes for the period of 2000–2009, Buyuksahin and Harris (2011) argue that during this period, non-commercial net position changes are driven by price changes in crude oil futures, but not vice versa. In addition, they divide non-commercials into hedge funds (including commodity pool operators, commodity trading advisors, associated persons controlling customer accounts, and other managed money traders) and floor brokers & traders, and find that hedge funds remain in line with the above argument, but floor brokers & traders contribute to price changes in crude oil futures.

Different from other studies, Irwin and Sanders (2012) identify the CFTC's Index Investment Data (IID) as the index funds positions, and find that index funds are not the cause of price changes in commodity futures during 2007-2011. Afterwards, Sanders and Irwin (2014) prove again at the firm level that fund positions are unrelated to price movements in WTI crude oil futures market.

Among the above studies on the interaction analysis, the Granger causality test is the most common method, and a number of new test methods have been developed since Granger (1969) proposes the concept of Granger causality. For example, Sims (1972) introduces the VAR model, which is now a very user-friendly method. Based on the work of Sims (1972), the VECM, GARCH and other models are also introduced into the Granger causality test. In addition, Haugh (1976) first constructs the statistic based on cross-correlation coefficients to examine the dependence of two time series which implies Granger causality. Haugh's statistic advances the cumulative effect of long-time information spillover but cannot determine the effect in different time periods. Accordingly, Hong (2001) solves this problem with the kernel function. It should be noted that the methods above are mainly applied to the linear relationship (Baek & Brock, 1992; Hiemstra & Jones, 1993); however, financial time series generally exists significant nonlinear characteristics (Hsieh, 1989, 1991; Zhang, Yao, He, & Ripple, 2019). Against this backdrop, Baek and Brock (1992) propose the nonlinear Granger causality test, and then Hiemstra and Jones (1994) modify Baek and Brock’s version based on the non-parametric estimators and apply it to the relationship research on stock price-volume. Besides, the Hiemstra-Jones test has been used in crude oil market as well (Moosa & Sil vapulle, 2000). To avoid the over-rejection in the Hiemstra-Jones test, Diks and Panchenko (2006) propose a new statistic to test the nonlinear relationship between two series.

However, the methods described above almost only investigate the general relationship during the whole sample period in the mean sense, which produces a constant value, but do not accurately consider the relationship over time. In fact, a few studies have made some attempt on this aspect. For instance, Sato et al. (2006) expand a wavelet dynamic vector auto-regressive (DVAR) approach and apply it to the time-varying Granger causality. Under the hypothesis that the VAR including time-varying coefficients is subject to a smooth break in the coefficients of the Granger causal variables, Christopoulos and León-Ledesma (2008) use the logit smooth transition autoregressive (LSTAR) model with time as the transition variable to examine the time-varying Granger causality. Besides, based on Haugh (1976) and Hong (2001), Lu and Hong (2012) construct the time-varying information spillover statistics by introducing a suitable rolling window, which have been used in crude oil market (Jammazi, Ferrer, Jareno, & Shahzad, 2017). Additionally, Kolodziej et al. (2014) also explore the time-varying correlation between returns to the spot prices of WTI and equities by the Kalman Filter model and CAPM model.

In summary, it is notable that existing relevant studies have provided a significant quantity of methods and empirical explorations for the relationship between crude oil futures and financial positions, yet there are still many limitations that require further study. First, the actual relationship generally exists in linear and nonlinear forms but most studies have only focused on one form, such as the linear form. Second, existing studies have explored the general relationship over the whole sample period, or they may identify the influence changes of financial positions on crude oil futures by dividing the whole sample period into several sub-periods but not in a continuous manner. Therefore, to a large extent, their results are still in the mean and static sense. Thirdly, in the commonly-used Commitments of Traders Report (COT) from CFTC, the concept of non-commercials is wider than actual speculators or hedge funds. Therefore, it is not reasonable or scientific to regard non-commercial positions as speculative positions. Finally, most existing studies focus on the collapse of crude oil prices in 2008, but fewer report that in 2014. Therefore, the main purpose of this paper is to explore the dynamic relationship between crude oil futures and speculative positions, and compare the causes of collapse of crude oil futures in 2008 and 2014, which may be of practical significance to the market analysts and regulators.

3. Methods and data definitions

3.1. Methods

3.1.1. Linear Granger causality test

The traditional linear Granger causality test (Granger, 1969) has been used widely, and the most common test is generally based on the VAR model, which is specified as Eq. (1), including two stationary time series \{x_t\} and \{y_t\}.

\[
\begin{align*}
    x_t &= A_1(L)x_t + A_2(L)y_t + U_{x,t}, \\
    y_t &= A_3(L)x_t + A_4(L)y_t + U_{y,t},
\end{align*}
\]

where \(A_1(L), A_2(L), A_3(L)\) and \(A_4(L)\) are lag polynomials with roots outside the unit circle, and the error terms \(U_{x,t}\) and \(U_{y,t}\) are i.i.d.
processes with zero mean and constant variance. Time series \{y_t\} may Granger cause \{x_t\} if any coefficients in \(A_2(L)\) are significantly different from zero. The bidirectional causality exists if both \(A_2(L)\) and \(A_3(L)\) joint tests are significantly different from zero.

3.1.2. Nonlinear granger causality test

Before the nonlinear Granger causality test, it should be determined whether the time series displays nonlinear characteristics according to the Brock, Dechert and Scheinkman (BDS) test (Brock, Scheinkman, Dechert, & Lebaron, 1996). For filtering the linear effect, the BDS test is applied to the residuals after the Auto-Regressive and Moving Average (ARMA) model application. Then, according to Diks and Panchenko (2006), the null hypothesis that time series \{y_t\} does not Granger cause \{x_t\} can be implied by Eq. (2):

\[
q = E[f_{XZ}(x,y,z)f_{Y}(x) - f_{XZ}(x,y)f_{Y}(z)] = 0
\]

where \(f_w(w)\) is the joint probability function, \(X_t = (x_t, y_t, z_t)\) is a \(L_x + L_y + 1\)-dimensional vector, including \(X_t \equiv (X_{t-L_x+1}, X_{t-L_x+2}, \ldots, X_t), Y_t \equiv (Y_{t-L_y+1}, Y_{t-L_y+2}, \ldots, Y_t),\) and \(Z_t = X_{t+1}\). The estimator of \(q\) can be expressed as \(T_n(\varepsilon)\), whose calculation can be simplified into Eq. (3):

\[
T_n(\varepsilon) = \frac{(2\epsilon)^{d_x+d_y+d_z}}{n} \sum_{i} \tilde{r}_0(W_i)
\]

with \(W_i = (X_{t-i}^L, Y_{t-i}^L, Z_t), i = 1, \ldots, n,\) and

\[
\tilde{r}_0(W_i) = \frac{1}{3} \left[ f_{XZ}^3(X_t, Y_t, Z_t)f_{X}(X_t) - f_{XZ}^2(X_t, Y_t)f_{XZ}(X_t, Z_t) + f_{XZ}^2(X_t, Y_t)f_{XZ}(X_t, Z_t) - f_{XZ}(X_t, Y_t)f_{XZ}(X_t, Z_t) \right]
\]

\[
+ \frac{1}{3n} \sum_j \left[ \hat{I}_{X}^j f_{XZ}^3(X_t, Y_t, Z_t)(2\epsilon)^{-d_z} + \hat{I}_{Y}^j f_{XZ}^3(X_t, Y_t, Z_t)(2\epsilon)^{-d_y} \right]
\]

\[
- \hat{I}_{Y}^j f_{XZ}^3(X_t, Y_t, Z_t)(2\epsilon)^{-d_x} - \hat{I}_{Z}^j f_{XZ}^3(X_t, Y_t, Z_t)(2\epsilon)^{-d_z} - \hat{I}_{X}^j f_{XZ}^3(X_t, Y_t, Z_t)(2\epsilon)^{-d_x} - \hat{I}_{Z}^j f_{XZ}^3(X_t, Y_t, Z_t)(2\epsilon)^{-d_y}
\]

where \(n = N - \max(L_x, L_y)\) is the effective sample size, \(d_x, d_y, d_z\) are the dimension of \(X_t, Y_t, Z_t, \tilde{r}_0(W_i)\) is the estimator of \(r_0(W_i)\) which is an asymptotic value used to calculate \(T_n(\varepsilon)\) (see Appendix A in Diks & Panchenko, 2006), \(\hat{I}_y^j\) is the indicator function and equals one if \(||W_i - W_j|| \leq \varepsilon\) and zero otherwise, \(\tilde{f}_w(w)\) is the estimator of a \(d_w\)-variate random vector \(W\) at \(W_i\) as Eq. (5), and \(\varepsilon\) is the bandwidth whose asymptotically optimal choice is given by Eq. (6).

\[
\tilde{f}_w(W_i) = \frac{(2\epsilon)^{-d_w}}{n - 1} \sum_{ij}^w \hat{I}_y^j
\]

\[
\epsilon* = \min \left( C^* n^{-\frac{1}{2}}, 1.5 \right)
\]

where \(C^*\) is a constant determined by the distribution of time series.

The \(U\)-statistic \(T_n(\varepsilon)\) satisfies \(T = \sqrt{n} \frac{T_n(\varepsilon) - d}{\sqrt{\sigma^2}} \sim N(0, 1)\) under the null hypothesis of i.i.d. For convenience, the estimator of \(r_0(W_i)\) proposed by Diks and Panchenko (2006) is used to calculate the approximate variance of \(T_n(\varepsilon)\), i.e., \(\hat{\sigma}^2 = 9\text{Var}(\tilde{r}_0(W_i))\). Based on the upper-tailed test in the asymptotic result, we can say that \(\{y_t\}\) strictly nonlinearly Granger causes \(\{x_t\}\) when the test statistic exceeds the critical values.

3.1.3. Time-varying information spillover statistic

(1) White noises

Suppose two independent time series \(\{w_{1,t}\}, i = 1, 2,\) are seen as stationary ARMA-GARCH processes. The residuals are standardized based on Eq. (7) after the ARMA-GARCH models used for each time series.

\[
\left\{ e_{ij} = \frac{u_{ij}}{\sqrt{h_{ij}}} \right\}, i = 1, 2
\]

where \(u_{ij}\) and \(h_{ij}\) are the residuals and variances of the ARMA-GARCH models, respectively.
(2) Size of rolling window

Let $M$ be the size of the rolling window, then $|t - M + 1, t|$ is constructed as the window period. Hong’s statistics follow an asymptotic $N(0, 1)$ distribution, so the value of $M$ needs to be sufficiently large. However, changes of information spillover are smoothed when $M$ is too large. In such a situation, according to Lu and Hong (2012), $M$ is singled out based on Eq. (8).

$$M = \frac{2(z_{1-0} + z_{1-\beta/2})^2}{\Delta^2} = \frac{2(z_{1-0} + z_{1-\beta/2})^2}{\Delta^2}$$

(8)

where $z_{1-\beta/2}$ is the critical value under the significance level $\beta$ in the $N(0, 1)$ distribution, $\alpha$ is the probability of type-one error, $\beta$ is the probability of type-two error and $\Delta = \frac{\alpha - 2\beta}{\alpha}$ is the standardized difference between mean values.

(3) Time-varying statistics

As for two standardized residual series in the window period, let $r_j(j, M)$ be the cross-correlation of lag order $j$ as Eq. (9).

$$r_j(j, M) = \begin{cases} \sum_{i=0}^{M-j-1} e_{1,i}e_{2,j-i} & j = 0, 1, \ldots, M - 1 \\ \sqrt{\sum_{i=0}^{M-j-1} e_{1,i}^2 \sum_{j=0}^{M-1} e_{2,j-i}^2} & j = -1, -2, \ldots, 1 - M \\ \sqrt{\sum_{i=0}^{M-j-1} e_{1,i}^2 \sum_{j=0}^{M-1} e_{2,j-i}^2} & \text{otherwise} \end{cases}$$

(9)

Then, Hong’s time-varying information spillover statistics are specified as Eqs. (10a) and (10b). The unidirectional statistic for information spillover from time series $\{v_2\}$ to $\{v_1\}$ at time $t$ is $H_1(k, M)$:

$$H_1(k, M) = \left[ M \sum_{j=1}^{M-i-1} K^2 \left( \frac{j}{k} \right) r_j(j, M) - D_1 \right] / (2E_1)^2$$

(10a)

and the bidirectional statistic is $H_2(k, M)$:

$$H_2(k, M) = \left[ M \sum_{j=2}^{M-i-1} K^2 \left( \frac{j}{k} \right) r_j(j, M) - D_2 \right] / (2E_2)^2$$

(10b)

where $k$ is the effective lag order, $D_1, D_2, E_1$ and $E_2$ are constants determined by the kernel function $K(a)$. Since Lu, Hong, Wang, Lai, and Liu (2014) and Jammazi et al. (2017) state that lagged dynamic correlations usually tend to be zero with large lags in financial markets, the Bartlett kernel function is applied in this paper (Priestley, 1981), as shown in Eq. (11).

$$K(a) = \begin{cases} 1 - |a|, & |a| \leq 1 \\ 0, & \text{otherwise} \end{cases}$$

(11)

Under the null hypothesis that two time series are i.i.d., when $M \to \infty$, the two statistics show an asymptotic $N(0, 1)$ distribution, i.e., $H_1(k, M) \sim N(0, 1)$ and $H_2(k, M) \sim N(0, 1)$. Then, if the statistic exceeds the upper-tailed $N(0, 1)$ critical values, we can say that there exists significant spillover at time $t$.

3.1.4. Time-varying DP Granger test

To capture the dynamic relationship between two time series, we also introduce a rolling window into statistic $T$ in the DP Granger test according to Hong’s information spillover statistics. The statistic $T^*$ at time $t$ is specified as:

$$T^* = \sqrt{m} \frac{T_{at}(m)}{\sigma} d N(0, 1), \sigma^2 = 9 \text{Var}(\gamma(t)), i \in [t - m, t - 1]$$

(12)

where $m = M - \max(L_\alpha, L_\gamma)$ is the effective size of rolling window. Similarly, the upper-tailed test is used for statistic $T^*$. We can say that $\{y_t\}$ strictly nonlinearly Granger causes $\{x_t\}$ at time $t$ when the test statistic exceeds the critical values.

3.2. Data descriptions

The positions of institutional investors in crude oil futures market can be reflected generally by the reports of CFTC on each Friday. These reports are divided into two categories: Commitments of Traders Report (COT) and Disaggregated Commitments of Traders.
Report (DCOT). Both reports provide a breakdown of open interest on each Tuesday, which are divided into two categories: reportable and non-reportable positions.\(^3\) The difference between the two reports is the classification of reportable positions. Traders are classified as ‘commercial’ or ‘non-commercial’ in the COT reports. And the classification is more detailed in the DCOT reports, which involves ‘Money Manager’, ‘Producer/Merchant/Processor/User’, ‘Swap Dealer’, and ‘Other Reportables’. Money Managers are defined as traders who are engaged in managing and conducting organized futures trading on behalf of clients, and generally regarded as hedge funds (Buyuksahin & Harris, 2011). Hence, this paper defines the positions of Money Managers in the DCOT reports as the positions of hedge funds.

As the prices of crude oil futures on the New York Mercantile Exchange (NYMEX) are dominant in the world (Liu, Schultz, & Swieringa, 2014), thus the Tuesday to Tuesday closing prices of the Cushing, Oklahoma, Crude Oil Future Contract 1 (RCLC1) of WTI traded in the NYMEX are selected as crude oil futures prices in this paper, which are obtained from the website of Energy Information Administration (EIA) of United States. In addition, to study the relationship changes between crude oil futures returns and hedge funds’ net positions during the collapse of crude oil prices in 2008 and 2014, this paper traces back to June 13th, 2006, when the earliest data of the DCOT are available. In the end, the sample period ranges from 6/13/2006 to 12/26/2017.

Fig. 1 presents the dynamics of crude oil futures prices (Price) and total open interests (TO) over the sample period. We can find that prior to 2014, crude oil futures prices and open interest appeared to have similar trends. However, after 2014, although crude oil futures prices experienced significant crashes and fluctuated at the relatively lower level, the total open interest remained an upward trend.

Fig. 2 shows the total open interests, the total positions of hedge funds and their proportions (i.e., TO, TOO_HF and PTO_HF, respectively) increased prior to the boom of crude oil futures prices in 2008. Although both slightly decreased following the collapse in

---

\(^3\) According to the explanatory notes of CFTC, reportable positions show the futures and options positions of traders whose positions meet or exceed specific reporting levels set by CFTC regulations, and are generally regarded as companies and institutional investors, whereas non-reportable positions involve traders whose positions do not meet the levels, and are generally regarded as small traders.
crude oil futures prices, they have increased steadily in recent years, which reflects the increasingly important role of hedge funds in international crude oil futures market.

Fig. 3 depicts the total positions and net positions of hedge funds as well as crude oil futures prices (i.e., TO_HF, HFNL and Price, respectively). We can see that the trend coordination between crude oil futures prices and hedge funds’ net positions outweighs that between crude oil futures prices and hedge funds’ total positions. The hedge funds’ total positions have shown an upward trend similar to crude oil futures prices from early-2009 to mid-2011 but not after 2014. Comparatively, the trend of hedge funds’ net positions is basically consistent with crude oil futures prices in the whole sample period. This shows that hedge funds’ net positions are more sensitive than hedge funds’ total positions to the price changes of crude oil futures.

Table 1 presents the descriptive statistics for crude oil futures returns and hedge funds’ net positions. The JB statistic for the two time series is statistically significant at the 1% significance level, indicating that they do not follow the normal distribution. According to the skewness and kurtosis, we can say that crude oil futures returns and hedge funds’ net positions both follow the leptokurtic and left-skewness distribution. The Ljung-Box Q-statistic of lag order 12 shows the null hypothesis of independent series is rejected at the 1% significance level for hedge funds’ net positions and 5% significance level for crude oil futures returns. Therefore, we can say that both series are auto-correlated. In addition, based on the ARCH LM-statistic, we can see that both series may present nonlinear dependence due to their clustering effects (ARCH tests are based on the ARMA model). This is consistent with the observations that returns in the futures markets generally show a fat tail, auto-correlation and volatility clustering features (Baum & Zerilli, 2016).

Moreover, the time series stationarity is tested based on the unit roots with the Augmented Dickey–Fuller (ADF), Phillips–Perron (PP) and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) approaches. Table 2 shows that both crude oil futures returns and hedge funds’ net positions appear to be stationary, so the VAR model can be developed subsequently. Meanwhile, the BDS test results show that the null
hypothesis of i.i.d. is rejected at the 1% significance level for crude oil futures returns and hedge funds’ net positions. It can therefore be inferred that a nonlinear relationship exists between them.

4. Empirical results and analyses

4.1. The Granger causality results

The Granger causality test is based on the VAR model with the lag order 1, which is selected by the SIC values. According to the linear and nonlinear Granger causality tests mentioned in section 3.1, the results are displayed in Table 3.

The results in Table 3 show that hedge funds’ net positions may Granger cause crude oil futures returns in the linear form but other results are rather weak. According to the linear results, hedge funds’ net positions may Granger cause crude oil futures returns at the 1% significance level, but crude oil futures returns may Granger cause hedge funds’ net positions just at the 10% significance level. In the nonlinear results, hedge funds’ net positions may Granger cause crude oil futures returns at the 10% significance level with lag order

---

4 Detailed results can be obtained upon request from authors.
Granger causality test results.

Panel A: Linear Granger causality test

\[ H_0: \text{LNHFNL does not Granger cause } \text{Return} \]

\[ H_0: \text{Return does not Granger cause LNHFNL} \]

<table>
<thead>
<tr>
<th>(L_x = L_y)</th>
<th>Statistic</th>
<th>(t)</th>
<th>(p)-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.4845</td>
<td>0.0688</td>
<td>1.1445</td>
</tr>
<tr>
<td>2</td>
<td>1.2117</td>
<td>0.1128</td>
<td>1.0206</td>
</tr>
<tr>
<td>3</td>
<td>0.8433</td>
<td>0.1995</td>
<td>1.6189</td>
</tr>
<tr>
<td>4</td>
<td>0.5338</td>
<td>0.2974</td>
<td>1.5148</td>
</tr>
<tr>
<td>5</td>
<td>0.4633</td>
<td>0.3216</td>
<td>1.3459</td>
</tr>
<tr>
<td>6</td>
<td>0.4271</td>
<td>0.3184</td>
<td>0.9965</td>
</tr>
<tr>
<td>7</td>
<td>0.8651</td>
<td>0.1935</td>
<td>0.8286</td>
</tr>
<tr>
<td>8</td>
<td>0.8166</td>
<td>0.2071</td>
<td>0.551</td>
</tr>
</tbody>
</table>

Note: As suggested by Diks and Panchenko (2006), we set the constant \(C = 8\) in Eq. (6), then the optimal bandwidth \(k = 1.29\) and the number of lags \(L_x = L_y = 1, 2, \ldots, 8\) in the nonlinear Granger test.

\(L_x = L_y = 1\), and crude oil futures returns may Granger cause hedge funds’ net positions at the 10% significance level with lag order \(L_x = L_y = 3, 4, 5\). Moreover, according to the \(p\)-value, the linear effect of hedge funds’ net positions on crude oil futures returns is stronger than the nonlinear effect, which is consistent with Zhang (2013) but in contrast to Irwin and Sanders (2012) and Sanders and Irwin (2014). The reason for the divergence may be the use of different positions.

4.2. The time-varying information spillover test results

Hong’s time-varying information spillover tests (see Eq. (10)) are applied to the ARMA-GARCH standardized residuals corresponding to crude oil futures returns and hedge funds’ net positions. According to the ARCH-LM test, the null hypothesis of all regression coefficients in the ARCH model being jointly zero can be accepted at the 5% significance level. It can therefore be inferred that the two ARMA-GARCH models basically eliminate the clustering effects.
According to the Monte Carlo simulation results of Lu and Hong (2012), the efficiency of Hong's time-varying information spillover tests is slightly affected by the selection of lag order $k$ and rolling window size $M$. Thus we follow Lu and Hong (2012) to set $k = 10$ in Eq. (10). According to the construction of statistics in Eq. (10), Hong's time-varying test cannot present the changes of correlations between two time series during sample period $t \in [1, M - 1]$. To capture the relationship between crude oil futures returns and hedge funds' net positions before the outbreak of financial crisis in 2008, we choose a smaller rolling window size $M = 64$ when $\alpha = 0.05$, $\beta = 0.2$ and $\Delta = 0.5$ in Eq. (8) proposed by Lu and Hong (2012).7 The results of Hong's time-varying information spillover tests are shown in Fig. 4.

To show the result more clearly, the simple formula $\ln(1/p)$ is applied in Fig. 4. Based on Fig. 4, it can be found that the relationship between crude oil futures returns and hedge funds' net positions has evident time-varying characteristics. For most of the sample period, the $P$-values of bidirectional statistic (see Eq. (10b)) are below 1%, which reflects the significant bidirectional spillover between crude oil futures returns and hedge funds' net positions. Meanwhile, the $P$-values of the unidirectional information spillover statistic (see Eq. (10a)) from crude oil futures returns to hedge funds' net positions are below 5% during September and December 2010, February to November 2014 and April to December 2017, and below 1% during February to October 2014 and May to December 2017. Conversely, the information spillover from hedge funds' net positions to crude oil futures returns clusters during April to July 2008, January to February 2016, and June to November 2017 when the $P$-values are below 5%, and during July and October 2017 when the $P$-values are below 1%.

Prior to the global financial crisis in 2008, WTI crude oil bubbles were pushed by speculative behaviors and had increased rapidly since 2007 (Zhang & Yao, 2016). The information spillover from hedge funds' net positions to crude oil futures returns became significant during April to July 2008. In order to address the financial crisis, since the end of 2008, most countries including Europe members and USA have implemented a series of expansionary fiscal policies and loosened monetary policies, which have attracted hedge funds to flood into crude oil futures markets (Chen, Filardo, He, & Zhu, 2016; Cukierman, 2013; Grammatikos, Lehnert, & Otsubo, 2015), and hedge funds' net positions have increased again. However, in 2010, the Dodd-Frank Act's Title IV required financial institutions including hedge funds to offer more transparent disclosure (US Congress, 2010), which is a disadvantage to the excessive speculation of hedge funds. Based on these grounds, the information spillover from hedge funds' net positions to crude oil futures returns strengthened significantly in 2009 but weakened sharply in 2010. Since the limit crude oil production of OPEC and Russia from 2016, the increasing crude oil prices have attracted hedge funds to flood into crude oil futures markets again. According to the mechanism of positive feedback (Tokic, 2011), hedge funds pushed the crude oil prices up further, which strengthened the effect of hedge funds' net positions on crude oil futures returns again.

---

7 The result with lower probability of type-two error $\beta = 0.05$ and $M = 100$ is similar to the result in this paper.
Besides, there exists significant unidirectional information spillover from crude oil futures returns to hedge funds’ net positions when crude oil futures prices are highly volatile, and there is significant unidirectional information spillover in turn when crude oil futures prices continue to rise. Combining Figs. 3 and 4, we can find that crude oil price experienced rapid rise and sharp decline during the whole 2008 and June 2010 to October 2011 when the unidirectional information spillover from crude oil futures returns to hedge funds’ net positions has been strengthened, and the P-values are even below 1% during the crash in 2014 and the continuous rise of crude oil prices in the second half of 2017. On the other hand, the hedge funds’ net positions increased sharply during April to May 2008, June to November 2009, January to March 2016 and July to October 2017 whilst crude oil futures prices experienced rising continually. During most of these periods, the P-values of the unidirectional information spillover statistic from hedge funds’ net positions to crude oil futures returns are below 5%, which means hedge funds have significant influence on crude oil futures prices and tend to put them up. Based on the analysis above, high volatility of crude oil futures prices strengthens the influence of crude oil futures returns on hedge funds’ net positions, which is in agreement with the results of Buyuksahin and Harris (2011). And the result also indicates that hedge funds’ net positions have evident effect on crude oil futures returns when crude oil futures prices continue to rise. This proves the positive feedback mechanism of De Long et al. (1991) and Tokic (2011).

Finally, comparing the significance of unidirectional information spillover from hedge funds’ net positions to crude oil futures returns in 2008 and 2014, we find that the bubbles in crude oil futures prices in which hedge funds play an important role contribute to the crash of crude oil futures prices in 2008, but hedge funds have no significant effect on the crude oil futures price crash in 2014. According to Figs. 3 and 4, the information spillover from hedge funds’ net positions to crude oil futures returns remained significant when crude oil futures prices rose rapidly in 2008, meaning that hedge funds’ net positions have linear shock on crude oil futures returns during this period. For instance, in the first half of 2008, hedge funds increased net positions and pushed up the bubbles in crude oil futures market under excessive supply of crude oil. This validates the explanation of Tokic (2011) that the speculators play an important role in pushing up crude oil prices bubbles in 2008. However, when crude oil futures prices dropped again in the second half of 2014, the information spillover from hedge funds’ net positions to crude oil futures returns is significant only after the crash of crude oil futures prices. After weakening in 2009, the hedge funds’ net positions have no significant influence on crude oil futures returns until 2016.

4.3. The time-varying DP granger test results

To capture the dynamic relationship between crude oil futures returns and hedge funds’ net positions in the nonlinear form, the rolling window is introduced to the DP Granger test. As denoted by Yang and Zhang (2014), the DP Granger test can be more accurate when the window size reaches at least 200 and the lag order is equal to one. Thus, we set \( M = 200 \), \( L_x = L_y = 1 \) and \( \epsilon^* = 1.5 \) according to Eq. (6) in the time-varying DP Granger test, as shown in Fig. 5.

![Fig. 5. Time-varying DP Granger test results.](image-url)
Due to the large window size, the results are more smooth than the linear results and only present the relationship changes between crude oil futures returns and hedge funds’ net positions after 2010. However, the nonlinear characteristics are similar to the linear results. First, the crude oil futures returns have significant influence on hedge funds’ net positions during high volatility of crude oil futures prices. When the crude oil futures prices experience drastic fluctuations after 2014, the $P$-values of the DP Granger test from crude oil futures returns to hedge funds’ net positions keep below 1%. Second, the hedge funds’ net positions have significant influence on crude oil futures returns when the crude oil futures prices rise continuously. The $P$-values of the DP Granger test from hedge funds’ net positions to crude oil futures returns remain below 5% after the crude oil futures prices bottom out and rise in 2016. Finally, we also find that hedge funds are not the main reason for the crash of crude oil futures prices in 2014, since hedge funds’ net positions have no significant influence on crude oil futures returns during this period.

Both linear and nonlinear results prove that hedge funds are not the main reason for the crash of crude oil futures prices in 2014. According to the study of Zhang and Yao (2016), market fundamentals were the main driver of WTI crude oil price drop during 2014 and 2015. In 2014, due to increasing production in shale gas fields, American crude oil production significantly exceeded expected output. In addition, traditional crude oil exporting countries such as Libya and Iraq resumed production. In October 2014, OPEC’s crude oil production reached 30.25 million barrels per day, which was higher than the production ceiling of 30 million barrels per day (OPEC, 2014). In the case of slow growth in demand, the substantial increase of crude oil supply and dramatic appreciation of the US dollar jointly contributed to the drop of crude oil prices.

5. Concluding remarks

In this paper, the linear and nonlinear Granger causality tests as well as Hong's time-varying information spillover test and time-varying DP Granger test are used to explore the relationship between crude oil futures returns and hedge funds’ net positions from 2006 to 2017. Some main conclusions are soundly drawn as follows:

First of all, hedge funds’ net positions have significant effect on crude oil futures returns in the linear form but their nonlinear influence is much weaker. In general, hedge funds’ net positions may Granger cause crude oil futures returns at the 5% significance level in the linear form, but not vice versa. Additionally, the results of DP Granger test are not significant at the 5% level.

Second, both the linear and nonlinear relationship between crude oil futures returns and hedge funds’ net positions has time-varying characteristics, and the influence of crude oil futures prices has been evidently strengthened when they experience high volatility whilst the influence of hedge funds’ net positions has been strengthened only when crude oil futures prices rise substantially. Besides, the correlation between crude oil futures returns and hedge funds’ net positions has become increasingly stronger since the crude oil futures price crash in 2014.

Finally, hedge funds play an important role in pushing up bubbles in crude oil futures prices, which contribute to the crash of crude oil futures prices in 2008, but in 2014 crude oil price drop is mainly due to market fundamentals.

These conclusions may help crude oil futures investors to judge price tendency and related departments to develop appropriate policies. For example, considering the increasing influence of hedge funds in recent years, investors and policymakers should pay more attention to the positions of hedge funds as well as market fundamentals to forecast crude oil futures prices.

There is still much relevant work to do in the future. For instance, this paper analyzes the weekly data, and we can make further research if the daily data are available in the future. In addition, this paper examines the effect of hedge funds on the violent fluctuations in crude oil futures prices during 2008 and 2014, there are still some key factors which need to be considered in the future, such as economic, financial and credit.

Acknowledgments

We gratefully acknowledge the financial support from National Natural Science Foundation of China (nos. 71273028, 71322103, 71774051), National Program for Support of Top-notch Young Professionals (no. W02070325), Changjiang Scholars Program of the Ministry of Education of China (no. Q2016154), Hunan Youth Talent Program.

References


Dr. Yue-Jun Zhang is a Professor at Business School, Hunan University, China, as well as the Director of Center for Resource and Environmental Management, Hunan University. He got his PhD degree in Energy Economics from Chinese Academy of Sciences in 2009. His research interests include energy economics and policy modelling. Up to now, Dr. Zhang has published more than 80 articles in peer-reviewed journals, such as Energy Economics, Journal of Forecasting, Quantitative Finance, Economic Modelling, Energy Policy, Journal of Policy Modelling, Resources Policy. Dr. Zhang was a visiting scholar at Energy Studies Institute of National University of Singapore, and Lawrence Berkeley National Laboratory, USA.

Mr. Yao-Bin Wu is a graduate student at School of Management, Fudan University, China. His research interests focus on oil market modelling.