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Is WTI crude oil market becoming weakly efficient over time? New evidence from multiscale analysis based on detrended fluctuation analysis

Yudong Wang *, Li Liu

School of Finance, Nanjing University of Finance and Economics, PR China

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ABSTRACT

This paper extends the work in Tabak and Cajueiro [Are the crude oil markets becoming weakly efficient over time, Energy Economics 29 (2007) 28–36] and Alvarez-Ramirez et al. [Short-term predictability of crude oil markets: a detrended fluctuation analysis approach, Energy Economics 30 (2008) 2645–2656]. In this paper, we test for the efficiency of WTI crude oil market through observing the dynamic of local Hurst exponents employing the method of rolling window based on multiscale detrended fluctuation analysis. Empirical results show that short-term, medium-term and long-term behaviors were generally turning into efficient behavior over time. However, in this way, the results also show that the market did not evolve along stable conditions for long times. Multiscale analysis is also implemented based on multifractal detrended fluctuation analysis. We found that the small fluctuations of WTI crude oil market were persistent; however, the large fluctuations had high instability, both in the short- and long-terms. Our discussion is also extended by incorporating arguments from the crude oil market structure for explaining the different correlation dynamics.

1. Introduction

The pioneer, Peters (1991, 1994) using rescaled range analysis (R/S) detected the fractal structures of several capital markets. His results showed that financial markets were fractal and long-range correlated which was a great challenge to efficient market hypothesis (EMH). Until now, the R/S method has been widely used to investigate the long-range correlations in financial markets. Tabak and Cajueiro (2007) using the R/S method found evidence that crude oil markets were becoming more and more efficient over time. However, the results of the R/S method depend on the extreme values of the selected samples and are sensitive to the abnormal values of series. Thus, the R/S method cannot be used to analyze the long-range correlations of non-stationary series. Peng et al. (1994) proposed detrended fluctuation analysis (DFA) when they studied the correlations of molecular chains in deoxyribonucleic acid (DNA). This method avoids the spurious detection of apparent long-range correlations that are an artifact of patchiness and has become a widely used technique for the determination of (mono-)fractal scaling properties (Podobnik et al., 2006; Jiang et al., 2007 and Alvarez-Ramirez et al., 2008a, 2008b). By analyzing the scale behavior, one can obtain the situation of long-range correlations for different terms. For this reason, we extend the work in Tabak and Cajueiro (2007) by detecting the situations of efficiency through observing the dynamic of local Hurst exponents based on multiscale detrended fluctuation analysis.

Empirical results of testing for the efficiency of crude oil markets in the area of econophysics can only be found in few studies. As far as we know, the first work in this area is Alvarez-Ramirez et al. (2002). Alvarez-Ramirez et al. (2002) implemented multifractal Hurst analysis on crude oil prices of Brent, WTI and Dubai markets. Empirical results showed the characteristic time scales in the order of weeks and quarters and demonstrated that the crude oil market was consistent with the random walk behavior only at scales in the order of days to weeks. After Alvarez-Ramirez et al. (2002), Serletis and Andreadis (2004) using the R/S method and multifractal data analysis found a random fractal structure for North American energy markets. Besides Tabak and Cajueiro (2007), Elder and Serletis (2008) using a new semi-parametric wavelet-based estimator, which was superior to the more prevalent GPH estimator found evidence that energy prices displayed long memory (long-range correlations) and that the particular form of long memory was anti-persistence. As an extension, detrended moving average analysis (DMA) was employed in Serletis and Rosenberg (2007) with similarly empirical results. Based on the work above, Alvarez-Ramirez et al. (2008a) imposed detrended fluctuation analysis on the return series of three crude oil markets. Empirical results showed that the crude oil markets were consistent with efficient market hypothesis over long horizons. However, time varying short-term inefficient behavior became more and more efficient in the long-term.

In this paper, we find that WTI crude oil market was gradually close to random walk behavior for short, medium and long time scales

* Corresponding author. Wenyuan Road 3, Qixia District, Nanjing 210046, Jiangsu Province, PR China. Tel.: +86 13512513538.
E-mail address: wangyudongnj@126.com (Y. Wang).

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using time varying multiscale analysis, although there were two apparent "jumps" in the short-term correlation dynamics which were caused by supply shocks. That is also to say, short-term, medium-term and long-term behaviors were generally becoming more and more efficient over time. Our discussion is also extended using multifractal detrended fluctuation analysis proposed by Kantelhardt et al. (2002). By incorporating arguments from the crude oil market structure, we try to find the explanations of the different correlation dynamics.

This paper is organized as follows: we provide methodology and data description in Sections 2 and 3, respectively. Section 4 is empirical results and Section 5 is the discussion. Conclusion is shown at the last section.

2. Methodology

The method of DFA can be described as follows (Peng et al., 1994):

Let $\{x_t, t=1, \Lambda, N\}$ be a time series, where N is the length of the series.

Firstly, we determine the "profile"

$$y_k = \sum_{t=1}^{k} (x_t - \bar{x}),\ k = 1,2,\Lambda,N, \tag{1}$$

where $\bar{x}$ denotes the average value of the whole time series.

Secondly, we divide the profile $\{y_k\}_{k=1,\Lambda,N}$ into $N_s \equiv \mathrm{int}(N/s)$ non-overlapping segments of equal length s. Since the length N of the series is often not a multiple of the considered time scale s, a short part at the end of the profile may remain. In order not to disregard this part of the series, the same procedure is repeated starting from the opposite end. Thereby, $2N_s$ segments are obtained altogether. Introduced by Peng et al. (1994), we get $10<s<N_s/5$.

Thirdly, we calculate the local trend for each of the $2N_s$ segments by a least-square fit of the series. Then determine the variance

$$F^2(s,\lambda) \equiv \frac{1}{s}\sum_{j=1}^{s} [y_{(\lambda-1)s+j} - P_\lambda(j)]^2 \tag{2}$$

for $\lambda = 1, 2, \Lambda, N_s$ and

$$F^2(s,\lambda) \equiv \frac{1}{s}\sum_{j=1}^{s} [y_{N-(\lambda-N_s)s+j} - P_\lambda(j)]^2 \tag{3}$$

for $\lambda = N_s+1, N_s+2, \Lambda, 2N_s$. Here, $P_\lambda(j)$ is the fitting polynomial with order m in segment λ (conventionally, called mth order DFA and written as DFAm).

At last, we can get fluctuation function

$$F(s) = \sqrt{\frac{1}{2N_s}\sum_{\lambda=1}^{2N_s} F^2(s,\lambda)}. \tag{4}$$

In general, $F(s)$ obeys a power-law behavior

$$F(s) \propto s^H. \tag{5}$$

Here, the Hurst exponent H can be obtained by observing the slope of log–log plot of $F(s)$ versus s through the method of least squares. If $0.5<H<1.0$, we consider that the time series display the property of persistence; if $0<H<0.5$, we consider that the series display the property of anti-persistence. However, if $H=0.5$, the series display random walk behavior indicating that the market is efficient.

3. Data

We choose daily closing price data of the West Texas Intermediate (WTI) with the date from July 13, 1990 to March 6, 2009. The data are obtained from the Energy Information Administration in the US Department of Energy.

Let P_t denote the price of crude oil on day t. The daily price return, r_t, is calculated as its logarithmic difference, $r_t = \log(P_t) - \log(P_{t-1})$. The graphical representation of prices and returns of WTI is illustrated as Fig. 1.

4. Empirical results

At first, we analyze the scale behavior of the whole return series. From Peng et al. (1994), we set the least scale to be 1 and the greatest scale to be 3 (logarithmically). We find that the Hurst exponent is 0.4973 which seem to be very close to random walk behavior. However, through observing the log–log plot of $F(s)$ versus s in Fig. 2, it is apparent that a single line cannot fit the curve of $F(s)$ versus s. Just as words in Uritskaya and Serletis (2008): "Of course, there is no reason to expect that DFA functions of inefficient markets are described by constant α[1] values". Using multiscale analysis, we do not directly calculate the Hurst exponent by assessing the whole slope of $F(s)$ versus s. Dividing the whole time scale interval (Eqs. (1)–(3)) into ten sub-intervals with same length of 0.2, we calculate the Hurst exponent for each sub-interval of time scales by estimating the local slope of fluctuation function $F(s)$versus scale s. Thus, we can get the Hurst exponents for ten scale interval, $1<\log s<1.2$, $1.2<\log s<1.4$, …, $2.8<\log s<3$. The results are shown in Fig. 3.

We can see that for short scales ($1<\log s<1.2$ or $s<16$), the Hurst exponent is 0.5573 indicating the existence of persistence in the short-term which is generally consistent with Alvarez-Ramirez et al. (2008a). For medium scales ($1.2<\log s<2.2$ or $16<s<158$), the significant anti-persistence can be found indicating that the crude oil market was anti-persistent in the medium-term. For large scales ($\log s>2.2$ or $s>158$), the situation is not consistent.

To get the evolution of local situation in the short-, medium- and long-term, following Tabak and Cajueiro (2007), we employ the method of rolling windows which length is fixed to be 1008 b-days (about 4 years) to find out the dynamic of Hurst exponents. The step is fixed to be one b-day. In this case, the time interval of the first window is from July 1990 to July 1994. When we imposed DFA procedure on the observations in each rolling window, from Peng et al. (1994), the smallest scale is set to be 1 and the largest one is set to be 2.3. With window moving, the dynamics of local Hurst exponents for each window under different time scales are shown in Fig. 4. The date in x-axis stands for the last day of the sample in each window.

From Fig. 4, we can find the evolution of situation of short time scale behavior (the first row, first column of Fig. 4). Although the crude oil market emerged anti-persistence behavior after the year 2000, the local Hurst exponent curve seems to be attracted by the line of 0.5 after the year 2004. This trend is more apparent for the scale $1.2<\log s<1.4$ (the first row, second column of Fig. 4). That is to say the short-term inefficient behavior had a trend of gradually turning into efficient behavior in the long-term which is generally consistent with Alvarez-Ramirez et al. (2008a).

For the scale interval $1.4<\log s<1.6$ (or $25<s<40$, the second row, first column of Fig. 4), we can also find out the evidence of becoming more and more efficient. Before the year 2003, it changed under the value of 0.5 implying anti-persistent behavior. After 2003, the curve kept moving towards the value of 0.5 although the curve seemed to keep a downward trend recently. We can obtain a similar result that the general situation was becoming more and more efficient.

For the scale $1.6<\log s<1.8$ and $1.8<\log s<2$ (the second row, second column and the third row, first column of Fig. 4), the curve vacillated around 0.5 especially after 2000 indicating that the crude oil

[1] Here, α denotes Hurst exponent H.