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Q1 # A study on chaos in crude oil markets before and after 2008 international financial crisis

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HIGHLIGHTS

- Presence of chaos is investigated in crude oil markets before and after 2008 international financial crisis.
- No evidence of chaos is found in prices and returns.
- Strong evidence of chaos is found in volatilities after crisis.
- Crisis makes volatility less predictable.

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ABSTRACT

The purpose of this study is to investigate existence of chaos in crude oil markets (Brent and WTI) before and after recent 2008 international financial crisis. Largest Lyapunov exponent is estimated for prices, returns, and volatilities. The empirical results show strong evidence that chaos does not exist in prices and returns in both crude oil markets before and after international crisis. However, we find strong evidence of chaotic dynamics in both Brent and WTI volatilities after international financial crisis.

1. Introduction

A nonlinear system is chaotic when it is characterized by unpredictability and irregular motion. In particular, a chaotic system is a random-looking nonlinear deterministic process with irregular periodicity and sensitivity to initial conditions. Chaos tests have been widely employed to detect presence of chaos in numerous fields of engineering and science [1–8]. Besides, there is a growing interest in studying presence of chaos in financial and economic time series; particularly in stock markets [9,10] and exchange rates [10–13]. However, no particular attention has been given to crude oil markets to the best of our knowledge. Indeed, since crude oil plays a major role in international macroeconomics and finance and drives industrialized economies, several works in econophysics literature have been conducted to better understand the dynamics of crude oil price; including market segmentation [14], volatility forecasting [15], identification of multi-scale dynamic linkages between crude oil price and the stock market [16], multifractal analysis [17–19], asymmetry analysis in prices [20], cross correlation between crude oil and refined product prices [21,22], cross correlation between crude oil and cost to transport raw materials [23], cross correlation between crude oil and agricultural commodity markets [24], fractal analysis [25], co-movement between the stock and prices of crude oil and gold [26], and markets network modelling [27].

Some interesting results from the literature follow. In Ref. [17], it was found that for two Gulf Wars, the first one made greater impact on Brent and WTI; and particularly, Brent market was more influenced by Gulf Wars. In Ref. [28], the WTI

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oil futures market was found to be weak-form efficient for the time period from April 1983 to October 2012. Additionally, it was inefficient right after financial crashes (1985, 2008) and the Gulf War. More recently, in Ref. [18], it was found that China energy industry index returns and its volatility series all show multifractal behaviours. In Ref. [20], the authors found evidence that WTI negative price trends exhibit less persistence than positive price trends from January 1986 to December 2014. In Ref. [21] cross-correlations between WTI and refined product (conventional gasoline, heating oil, jet fuel) prices are significant and change over time for the time period January 1991 to December 2013. The relationships between WTI and refined product prices from April 1996 to March 2011 were investigated in Ref. [22], and empirical results showed that they are cointegrated and that nonlinear correlations are stronger in the long-term than in the short term. Further, empirical results showed that financial crisis in 2007–2008 caused a structural break of the cointegrating relationship. Based on fractal analysis, the authors in Ref. [25] found that price shock sequences in WTI and Brent exhibit time-clustering behaviour and long-range correlations during the time period from May 1987 to September 2012.

In short, it is concluded from previous works that financial crashes and Gulf wars affect fractality, cross-correlation, and cointegration in crude oil markets. Therefore, the contribution of our study is to enrich the literature by examining existence of chaos in crude oil markets; particularly, checking whether chaos is absent or present in crude oil markets before and after a major and recent international financial crisis. Indeed, such investigation allows finding out possibility of a random-looking nonlinear deterministic process with irregular periodicity in crude oil markets; especially, at price, return, and volatility level. This is interesting in order to better localize chaos and to better understand the behaviour of price, returns, and volatilities in times of crisis. Certainly, investors and economists are concerned by movements in prices and returns. We are also interested in estimating chaos in volatility series since it is important for risk managers because volatility is a proxy of risk, expectations, and amount of information arriving. To the best of our knowledge, such issue has not been examined in the literature.

The purpose of this paper is to test for presence of chaos in crude oil market price, returns, and volatility before and after 2008 international financial crisis. Indeed, few studies have considered studying the dynamics of financial and economic time series in times of political or economic instability to better understand their behaviour from an econophysics perspective [29–33]. Two crude oil major markets are considered in our study: West Texas Instruments (WTI) and Brent crude oil market. The WTI crude oil price reflects crude oil demand in USA; which is the second crude oil importing country after the European Union; and the Brent crude oil price reflects the international crude oil demand [17]. Therefore, chaos test is applied to check presence of chaos in prices, returns, and volatilities of WTI and Brent market before and after 2008 international financial crisis to understand their respective dynamics.

In our study, largest Lyapunov exponent is estimated and hypothesis test is performed following methodology in Refs. [9,10]. Indeed, the largest Lyapunov exponent is one of the most employed techniques to assess the presence of chaotic behaviour in data [1–13] as it is used to measure the rate of separation of two close trajectories in a dynamical system. In fact, it is used because of its suitability to check existence of chaos in nonlinear dynamic systems. Besides, in our study, volatility series are estimated by employing the exponential generalized autoregressive conditional heteroskedasticity (EGARCH) process [34]. The latter is chosen because unlike conventional GARCH model it does not impose restrictions on the parameters to be estimated, and also because it allows capturing asymmetric effects in volatility.

Our paper is organized as follows. The EGARCH process and largest Lyapunov exponent estimation approach are described in Section 2. In Section 3, data and empirical results are presented. Finally, Section 4 concludes the paper.

2. Methods

2.1. The EGARCH model

Let returns series r be defined as the first differences of the natural logarithmic price levels, for example $r_t = \log(P_t) - \log(P_{t-1})$ where P is the price level of the crude oil market, and t is the time script. In this study, the standard EGARCH(1,1) process is chosen to estimate volatility series as it is parsimonious and does not impose restrictions on parameters to force estimated volatility to be positive. The standard EGARCH(1,1) process is represented by:

$$r_t = \mu_t + \varepsilon_t \tag{1}$$

$$\varepsilon_t = \sigma_t z_t,\ z_t \propto NID\,(0, 1) \tag{2}$$

$$\log\left(\sigma_t^2\right) = \omega + \alpha\left[\left|\frac{\varepsilon_{t-1}}{\sqrt{\sigma_{t-1}^2}}\right| - \sqrt{\frac{2}{\pi}}\right] + \beta\log\left(\sigma_{t-1}^2\right) + \delta\frac{\varepsilon_{t-1}}{\sqrt{\sigma_{t-1}^2}} \tag{3}$$

where ω, α, β, and δ are parameters to be estimated, and ε is a white noise. For instance, ω is a constant, α is the symmetric effect of the model, β is the persistence in conditional volatility, and δ is the leverage effect. An interesting advantage of EGARCH process is that the conditional variance $\log\left(\sigma_t^2\right)$ used to represent volatility series is defined as an asymmetric function of lagged disturbances ε_{t-1}. Another advantage of using EGARCH process is that it allows capturing oscillations in the conditional variance $\log\left(\sigma_t^2\right)$ since the parameter β can be either positive or negative.

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