Energy Economics 32 (2010) 993–1000

Contents lists available at ScienceDirect

Energy Economics

journal homepage: www.elsevier.com/locate/eneco

Crude oil market efficiency and modeling: Insights from the multiscaling autocorrelation pattern

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ARTICLE INFO

Article history:
Received 10 February 2010
Received in revised form 27 April 2010
Accepted 28 April 2010
Available online 6 May 2010

JEL classification:
C14

Keywords:
Crude oil
Autocorrelations
Multiscaling pattern
Mean reversion

ABSTRACT

Empirical research on market inefficiencies focuses on the detection of autocorrelations in price time series. In the case of crude oil markets, statistical support is claimed for weak efficiency over a wide range of time-scales. However, the results are still controversial since theoretical arguments point to deviations from efficiency as prices tend to revert towards an equilibrium path. This paper studies the efficiency of crude oil markets by using lagged detrended fluctuation analysis (DFA) to detect delay effects in price autocorrelations quantified in terms of a multiscaling Hurst exponent (*i.e.*, autocorrelations are dependent of the time scale). Results based on spot price data for the period 1986–2009 indicate important deviations from efficiency associated to lagged autocorrelations, so imposing the random walk for crude oil prices has pronounced costs for forecasting. Evidences in favor of price reversion to a continuously evolving mean underscores the importance of adequately incorporating delay effects and multiscaling behavior in the modeling of crude oil price dynamics.

1. Introduction

Fair valuation of projects and securities for the crude oil industry, including exploration, extraction, distribution and chemical transformation, requires accurate stochastic modeling to describe the observed complex dynamics of prices and returns. For instance, the famous Black-Scholes option pricing formula assumes that the commodity price follows a geometric Brownian motion (Smith and McCardle, 1998). In this model, prices are expected to grow at some constant drift rate with the variance in future spot prices increasing in proportion to time. If prices increase (resp., decrease) more than anticipated in one time period, all future forecasts are increased (resp., decreased) proportionally. The attractiveness of this modeling approach is that it leads to closed-form solutions that can be easily used in practice.

The underlying idea behind the Brownian motion assumption is that, after removing a constant drift, the dynamics of the (logarithmic) price differences can be described as an uncorrelated process standing in for any and all sources of uncertainty in the price history of the commodity. In turn, this concept is linked to the idea that valuation fairness is possible because returns cannot be predicted for any time horizon. In financial theory, this is known as the efficient-market hypothesis (EMH), which asserts that financial markets are informationally efficient in the sense that prices on traded assets already reflect all known information[1], and instantly change to reflect new information (Fama, 1970). Therefore, according to theory, it is impossible to consistently outperform the market by using any information that the market already knows, except through luck. In its weak form, the EMH states that future prices cannot be predicted by analyzing price from the past. In this way, excess returns cannot be earned in the long run by using investment strategies based on historical share prices or other historical data. In turn, this implies that prices exhibit no serial dependencies, meaning that there are no patterns to asset prices, and so future price movements are determined entirely by information not contained in the price series. Such assumptions should imply that prices must follow a random walk.

In recent years, investors and researchers have disputed the EMH both empirically and theoretically. The normal occurrence of human errors in reasoning and information processing (*e.g.*, overconfidence, overreaction and information bias) has been used as a suitable framework by behavioral economist to explain information imperfections in financial and commodity markets (Kahneman and Tversky, 1979, 2000). On the other hand, empirical analysis has provided mixed results, although evidence hinting to market efficiency is poorly supported (Chen et al., 2003; Charles and Darne, 2009). Speculative bubbles can be considered as anomalies where the market often appears to be driven by buyers operating on irrational exuberance,

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[1] Information or news in the EMH is defined as anything that may affect prices that is unknowable in the present and thus appears randomly in the future.

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doi:10.1016/j.eneco.2010.04.013

who take little notice of underlying value. These bubbles are typically followed by an overreaction of frantic selling, allowing shrewd investors to buy stocks at bargain prices (Lo and MacKinlay, 2001).

The efficiency of crude oil markets is a subtle issue given that the market configuration involves governments, large-scale producers, consumers and investors. In this way, one could expect that the underlying market dynamics exhibit important deviations from the EMH. This paper focuses on the market efficiency issue by exploring the presence of autocorrelations in historic crude oil price dynamics. In contrast to existing results in the open literature, the present work considers delay effects acting in the formation of crude oil prices. The results found with this approach indicate that deviations from efficiency and the type of model to describe return dynamics are dependent of the forecasting horizon.

1.1. Literature review

Empirical studies of testing for the efficiency of crude oil markets have been oriented to exhibit the presence of long-term dependencies in historical spot price sequences. Alvarez-Ramirez et al. (2002) implemented multifractal Hurst analysis on crude oil prices, showing that the market was consistent with the random-walk behavior only at scales of the order of days to weeks. Serletis and Andreadis (2004) showed that price dynamics of North American energy markets can be explained from random fractal structures. Tabak and Cajueiro (2007) using the R/S method found evidence that crude oil markets are becoming more and more efficient over time. However, a drawback of the R/S method is its sensitivity to trends and short-term dependency (Lo, 1991), which can lead to biased estimation of long-term correlations. To overcome this problem, Alvarez-Ramirez et al. (2008) used detrended fluctuation analysis (DFA), a method suited for non-stationary series plagued with trends (Peng et al., 1994), to show that the crude oil markets are consistent with the EMH over long horizons, although time-varying autocorrelation can be exhibited for short time scales. Shambora and Rossiter (2007) used artificial neural network models to show that prices can be forecasted, casting doubts on the efficiency of crude oil markets. Wang and Liu (2010) used multiscale DFA to show that short-term, medium-term and long-term behaviors were generally turning into efficient behavior over time. Also, multifractality analysis suggested that small fluctuations of WTI crude oil market are persistent; however, large fluctuations display high instability, both in the short- and long-terms. Summing, up, empirical evidences have indicated that crude oil markets are not uniformly efficient (*i.e.*, over the whole time scale range) and that prices can be forecasted to some extent using empirical models (*e.g.*, ANNs). In this form, traditional valuation approaches based on the geometric Brownian motion assumption can yield biased results. Hence, unbiased valuation of projects and securities for the crude oil industry should consider the market complexity[2] and propose alternative forecasting models. Recently, a number of authors motivated by theoretical arguments have considered the use of mean-reverting (Ornstein-Uhlenbeck) (Pindyck, 1999; Smith and McCardle, 1999; Tvedt, 2002) and Poisson-based jump dynamics with structural change (Lee et al., 2010) processes as being more appropriate for crude oil market modeling.

A detailed understanding of historical price dynamics should be combined with theoretical arguments to develop accurate stochastic models for forecasting of crude oil prices and valuation of financial and investment instruments (Pindyck, 1999). Although recent results have shed some light on, *e.g.*, the existence of time-varying autocorrelations and the role of fractal integrating processes, the problem deserves more detailed analysis with improved methods. In principle, results obtained in this line should improve modeling considerations and enhance theoretical arguments. This work uses a lagged DFA (Alvarez-Ramirez et al., 2009) to characterize the multiscale pattern of crude oil prices. The motivation for using the lagged version of the DFA is that, similar to traditional autocorrelation analysis, maximal long-term correlations can be found for non-zero lags, reflecting delayed effects in the underlying stochastic process. Similar to the approach by Wang and Liu (2010), a scale-dependent Hurst exponent (multiscale pattern) is computed to explore changes of the autocorrelation strength induced by shocks persisting in different time scales. In contrast to previously reported results, the analysis show that the price dynamics are hardly consistent with the EMH, exhibiting important departures from a geometric Brownian motion assumption. Interestingly, the multiscaling pattern is not continuous, but shows two jumps at one-quarter and one-year time scales, which can be related to the intrinsic cycles of financial markets. The discussion is extended by incorporating arguments from the crude market structure (Hamilton, 2008) for explaining the autocorrelation pattern.

The paper is organized as follows. The data description is made in Section 2. The methodology, based on lagged DFA, is provided in Section 3. The empirical analysis is made in Section 4. The results discussion is given in Section 5. Conclusions are shown in Section 6.

2. Data

We study daily closing price data of the West Texas Intermediate (WTI) with the date from January 1st. 1986 to December 31, 2009. The data are obtained from Energy Information Administration (EIO) in the U.S. Department of Energy (http://tonto.eia.doe.gov). The

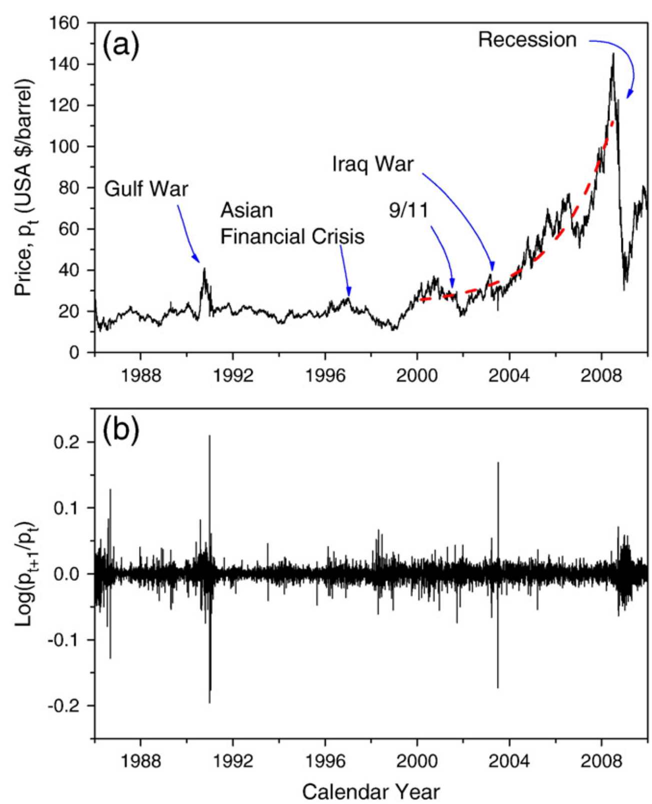

Fig. 1. (a) WTI price dynamics for the period ranging from 1996 to 2009. Some salient events that affected the market evolution are indicated. The current financial and economical recession induced the largest price variation in the recent three decades. Exponential price growth, indicated by a dotted line, can be observed for the period from 2000 to 2008, which is probably related to the high energy demand by China's fast economical growth. (b) Logarithmic price differences showing bursting periods associated to high price volatility.

[2] Complexity of crude oil markets emerges as a reflect of the interaction of numerous participants (producers, governments, consumers, etc.) and the effect of exogenous (economical, climatic, political, etc.) events (Hamilton, 2008).