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Efficiency of crude oil markets: Evidences from informational entropy analysis

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ABSTRACT

The role of crude oil as the main energy source for the global economic activity has motivated the discussion about the dynamics and causes of crude oil price changes. An accurate understanding of the issue should provide important guidelines for the design of optimal policies and government budget planning. Using daily data for WTI over the period January 1986–March 2011, we analyze the evolution of the informational complexity and efficiency for the crude oil market through multiscale entropy analysis. The results indicated that the crude oil market is informationally efficient over the scrutinized period except for two periods that correspond to the early 1990s and late 2000s US recessions. Overall, the results showed that deregulation has improved the operation of the market in the sense of making returns less predictable. On the other hand, there is some evidence that the probability of having a severe US economic recession increases as the informational efficiency decreases, which indicates that returns from crude oil markets are less uncertain during economic downturns.

1. Introduction

Energy and investment policy planning for many economic agents (e.g., firms and governments) requires an accurate knowledge of the complex mechanisms involved in price formation in crude oil markets and their relationship with economic dynamics and extreme (e.g., socio-political and meteorological) events. The possible relationships between crude oil prices and economic activity have been widely explored, suggesting that crude oil market dynamics have a direct effect on the economic cycle (Rasche and Tatom, 1977; Hamilton, 1983; Santini, 1985; Gisser and Goodwin, 1986; Rotemberg and Woodford, 1996; Carruth et al., 1998; Hamilton, 2003; Barsky and Kilian, 2004; Oladosu, 2009). Coincidences between high crude oil price increments and the outbreak of economic recessions have been documented (Hamilton, 1983; Mork, 1989), which suggest that crude oil price dynamics can be used as an indicative of the global economic activity. Other studies point towards that point towards permanent effects of crude oil prices on inflation and short-run but asymmetric effects on production growth rates (Cuñado and Perez de Gracia, 2003; Oladosu, 2009). Some studies have challenged the notion that movements of crude oil prices have significant effects on macroeconomic activity (Barsky and Kilian, 2004; Kilian, 2009). It has been also argued that the adverse effects of positive shocks can be explained from the resulting tightening of monetary policy (Bernanke et al., 1997) and that crude oil prices are significantly influenced by fluctuations in the Kilian economic index through both long-run equilibrium conditions and short-run impacts (He et al., 2010). Summing up, research results have indicated that crude oil markets have an important impact on the performance of regional and global economies and that this influence has a complex and multifactorial nature.

At the heart of the performance of crude oil markets is the concept of informational efficiency since oil price movements substantially affect, at different degrees and through different channels, the performance of most economic sectors and industries (Lescaroux and Mignon, 2008). The importance of the efficient market hypothesis (EMH) relies on the fact that in an efficient market all available and relevant information are fully and instantaneously reflected on the price of a market security so that no one can take advantage of this information (Fama, 1970, 1991). In this way, there are neither undervalued nor overvalued assets in an efficient market, and market price of financial assets constitutes a proper guide for capital budgeting and allocation. Arouri et al. (2010) have pointed out that market efficiency is desirable to asset pricing models and investor investment decision-making process; meanwhile it rests on strong assumptions such as, frictionless markets, information availability and transparency, investor rationality and arbitrage. Results regarding the fulfillment of the EMH should provide important insights in the dynamics of crude oil markets and their impact on worldwide and

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regional economies. In the following section, a literature review of the some salient contributions to the empirical analysis of crude oil market informational efficiency is provided. Subsequently, the main contribution of our work relative to existing results is described.

The remainder of the paper is organized as follows. Section 2 provides a review of the main results reported in the scientific literature. Section 3 describes the empirical entropy method used to characterize the dynamics of crude oil prices and to explore the possibility of sudden changes in market efficiency. Section 4 presents the data. Section 5 discusses the results obtained. Section 6 concludes the paper and suggests some policy implications arising from the results.

2. Literature review

Depending on the nature and source of the information, three forms of market efficiency can be established: strong form, semi-strong form, and weak-form efficiency (Fama, 1970, 1991). The set of available information can be both public and private information for the strong-form efficiency. It is limited to all public information for the semi-strong form and to all past price movements for the weak form. Most empirical tests for the EMH focus on the weak form. In this way, market efficiency is related to the absence of arbitrage conditions since the crude market behavior cannot be predicted using the dynamics of past price returns. Green and Mork (1991) used the generalized method of moments to show that the weak-form efficiency does not hold for the whole sample period 1978–1985. However, some efficiency improvements over time were observed for sub-sample periods. Alvarez-Ramirez et al. (2002) used multifractal Hurst analysis to find that the market was consistent with the random-walk behavior only at scales of the order of days to weeks. By using detrended fluctuation analysis of logarithmic price differences, Serletis and Andreadis (2004) showed that the price behavior of North American energy markets can be explained from random fractional Brownian motion dynamics, so that prices has long-run dependences. Tabak and Cajueiro (2007) used R/S analysis to find evidences that crude oil markets are becoming more and more efficient over time, which suggests that market deregulation introduced positive effects in market operation.

Recently, Alvarez-Ramirez et al. (2008) used methods based on detrended fluctuation analysis to show that crude oil markets are consistent with the EMH over long horizons, although time-varying autocorrelation can be exhibited for short time-scale. Maslyuk and Smyth (2008) used unit-root test to find that weekly crude oil price over the period 1991–2004 can be characterized as a random walk process with two structural breaks. Charles and Darné (2009) used variance ratio tests to show that Brent crude oil market is weak-form efficient while WTI crude oil market seems to be inefficient on the 1994–2008 subperiod. In contrast to Tabak and Cajueiro's research report, this result suggests that the deregulation has not improved the efficiency on the WTI crude oil market in the sense of making returns less predictable. By means of multiscale fluctuation analysis, Wang and Liu (2010) suggested that short-term, medium-term and long-term behaviors were generally turning into efficient behavior over time. Lean et al. (2010) found no evidence of mean-variance and stochastic dominance oil spot and future prices, inferring that there is no arbitrage opportunity between these two markets and spot and futures oil markets are efficient and rational. Alvarez-Ramirez et al. (2010) studied lagged fractal autocorrelations of spot WTI prices to find that autocorrelations can be masked by delay effects. Arouri et al. (2010) used state space models to find evidence of short-term predictability in crude oil prices over time, so the hypothesis of convergence towards weak-form informational efficiency should be rejected.

Some approaches have focused on the predictability of crude oil prices. Shambora and Rossiter (2007) used artificial neural network models with moving average crossover inputs to analyze crude oil future markets and showed that prices can be forecasted in the long-run, casting doubts on the efficiency of crude oil markets. Results from nonlinear approaches have suggested that the crude oil market is not efficient as the price dynamics can be predicted to some extent by using nonlinear models (Wang and Yang, 2010), genetic algorithms (Fan et al., 2008) and wavelet decomposition (Jammazi and Aloui, in press).

Overall, the empirical findings reported in the literature are still controversial since the results have been oriented to respond whether or not the crude oil price contains patterns that can be exploited to outperform the market. By recognizing the complexity of the problem, new results should be oriented to show not only that the market is efficient or not, but rather to provide a quantitative index of the crude oil market informational efficiency as well as to evaluate temporal changes that can be related to socioeconomic events. Next, concepts from informational entropy will be discussed to motivate their use for quantifying informational market efficiency in crude oil markets.

Although entropy is a powerful concept to characterize the diversity of patterns contained in a time series, its use to analyze financial time series has been constrained to a limited number of research studies. It is apparent that Gulko (1999) firstly proposed the use of entropy concepts to study financial time series by showing that the maximum-entropy formalism, also called informational efficiency, makes the efficient market hypothesis operational and testable. This formalism is used to establish that entropic markets admit no arbitrage and support both the Ross arbitrage pricing theory and the Black–Scholes stock option pricing model. Darbellay and Wuertz (2000) demonstrated the usefulness of entropy concepts to characterize financial time series by showing that the salient advantage of the entropy approach resides in its ability to account for nonlinear dependences in the autocorrelation structure of the underlying system dynamics (Kaffashi et al., 2008; Hassan et al., 2011). Pincus and Kalman (2004) suggested that approximate entropy algorithm is suitable for analyzing financial time series as it can be applied to very short sequences and can be used as a marker of market stability. Recently, entropy concepts have been used to quantify market efficiency in foreign exchange and stock markets. Since entropy is an index of the quantity of information (measured in terms of pattern richness) contained in a time series, high entropy can be related to low predictability of the market dynamics and, hence, to high market efficiency. In contrast to previous approaches focusing on an all-or-nothing response to the efficiency question, entropy can provide a relative degree of the efficiency of a given market. Oh et al. (2007) used the global foreign exchange market indices in order to study the efficiency of various foreign exchange markets around the market crisis. It was found that the markets with a larger liquidity (e.g., European and North American) have higher market efficiency than those with a smaller liquidity. Zunino et al. (2009) showed that degree of stock market inefficiency is negatively correlated with the permutation entropy. Risso (2008, 2009) used Shannon entropy concepts on symbolic dynamics of stock indices to show that the probability of having a crash increases as entropy decreases.

The aim of this work is to study the informational efficiency of crude oil markets by means of entropy analysis methods. The departing idea is that prices in efficient markets cannot be predicted because of the lack of intrinsic correlations and regular patterns. That is, the returns of a price trajectory for a market finding the weak-form of the EMH should correspond to uncorrelated stochastic