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Testing the evolution of crude oil market efficiency: Data have the conn

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HIGHLIGHTS

- We adopt a time-varying model to test the weak-form efficiency of crude oil markets.
- Weekly oil returns series have been extremely efficient during the past decade.
- Daily oil returns series have presented intermittent and inconsistent efficiency.
- Oil markets react asymmetrically to different information shocks.
- Policy recommendations are proposed according to the degree of efficiency

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ABSTRACT

Utilising a time-varying GAR (1)-TGARCH (1,1) model with different frequency data, we investigate the weak-form efficiency of major global crude oil spot markets in Europe, the US, the UAE and China for the period from December 2001 to August 2013. Our empirical results with weekly data indicate that all four markets have reached efficiency with few brief inefficient periods during the past decade, whereas the daily crude oil returns series suggest intermittent and inconsistent efficiency. We argue that the weekly Friday series fit the data better than the average series in autocorrelation tests. The evidence suggests that all four markets exhibit asymmetries in return-volatility reactions to different information shocks and that they react more strongly to bad news than to good news. The 2008 financial crisis has significantly affected the efficiency of oil markets. Furthermore, a comovement phenomenon and volatility spillover effects exist among the oil markets. Policy recommendations consistent with our empirical results are proposed, which address three issues: implementing prudential regulations, establishing an Asian pricing centre and improving transparency in crude oil spot markets.

1. Introduction

Research on the oil market has examined the theme of efficiency. Through the study of the evolution of crude oil market efficiency, we can not only clearly observe changes in market stability but also propose some relevant policy recommendations according to the degree of market efficiency.

Previous research on the efficiency of the crude oil market has focused on three main areas: methodology, time frequency and different markets. First, a variety of tests to examine the weak-form efficiency of the crude oil market already exist, such as the generalised method of moments (see, e.g., Green and Mork, 1991), new variance ratio tests (see, e.g., Charles and Darné, 2009), the method of generalised spectrum (see, e.g., Lv and Pan 2009), mean variance (MV) and stochastic dominance (SD) approaches (see, e.g., Lean et al., 2010a, 2010b) and detrended fluctuation analysis (see, e.g., Gu et al., 2010; Wang and Liu, 2010; Wang et al., 2011; Jiang et al., 2012).

These empirical methods rely primarily on time-invariant or some time variation regressions; however, gradual changes in the structure of the oil market make a time-varying parameter structure more compelling (Baumeister and Peersman, 2013a,b). We pay more attention to oil market dynamics than to the average behaviour of oil prices; therefore, unlike traditional methods for testing efficiency, this paper utilises a time-varying parameter model, which is considered a progressive efficiency research method (see, e.g., Li, 2003). When combined with the Kalman filter technique, a time-varying parameter model can clearly describe the evolution of oil market efficiency and accurately characterise the dynamic processes of the oil market ranging from invalidity to weak-form efficiency. In addition, the Kalman filter estimation is an updating method that bases the regression

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estimates for each time period on the previous period estimates and the data for the current period. This feature makes the method useful for investigating structural change in parameters and constructing forecasts based only on historical data (Hall and Cummis, 2005).

Three main types of time frequency exist: daily, weekly and monthly. Based on daily returns of the Brent and WTI markets, Tabak and Cajueiro (2007) find evidence that the markets have become more efficient over time. Ortiz-Cruz et al. (2012) utilise daily data from January 1986 to March 2011 to conclude that the WTI crude oil market has been efficient. Ozdemir et al. (2013) utilise the monthly crude oil spot and futures prices to investigate the efficiency of the Brent market and demonstrate that the market is characterised by weak-form efficiency. Arouri et al. (2010) utilise average weekly spot prices to study time-varying predictability in crude oil markets of Gulf Cooperation Council (GCC) countries, and they reject the hypothesis of convergence towards weak-form efficiency for all markets. However, we argue that utilising average weekly prices is inappropriate for autocorrelation tests and may lead to less reliable conclusions. In this paper, evidence suggests that utilising the Friday series rather than the Average series as weekly data for autocorrelation tests can better reflect the real situations of the crude oil markets.

Existing research on different markets includes various countries and regions and focuses on crude oil spot markets, futures markets, or both. Gülen (1998) contributes to the efficiency examining of crude oil futures market in several aspects such as much longer study time period. Kawamoto and Hamori (2011) study futures with different maturities and raise the concept of the "consistently efficient" market within an *n*-month maturity. By testing for the prices' random walk behaviour and quantifying the market inefficiency with a "multifractality degree", Wang and Wu (2012) find that the WTI future's market is more inefficient in the long run than in the short run. In addition, many other studies have tested the hypothesis of efficiency based both on crude oil spot and future's markets (see, e.g., Nilsson, 2008; Lean et al., 2010a, 2010b).

Unlike previous research relying primarily on the oil markets of WTI and Brent, we also include Dubai and Daqing. The WTI and Brent prices are utilised as the oil price benchmarks in the U.S. and European markets, respectively. Dubai oil is a leading benchmark for crude oil produced in the United Arab Emirates and is utilised in pricing sour crude, predominantly for pricing Middle East crude exports to Asia. The Daqing oil field is the largest in China and its crude oil output accounts for approximately 25% of national production. Because the Daqing price basically reflects crude oil prices in China, this paper selects the Daqing crude oil spot prices to represent Chinese crude oil prices.

We believe our results will be more persuasive because we consider all three areas described above. For the method, we employ a time-varying parameter model. Arouri et al. (2010) examine time-varying predictability in the crude oil markets of four Gulf Cooperation Council (GCC) countries, but rather than also applying their GARCH model, we adopt a TGARCH model, which can better observe asymmetries in return-volatility reactions to different information shocks. Moreover, we utilise a BEKK-GARCH model to assess co-movements and volatility spillover effects among the oil markets. Our approach to time frequency is also quite different from previous research because we feel that different conclusions may emerge from different time frequency data. We utilise both daily closing returns and Friday closing returns for the empirical modelling and average weekly returns and Wednesday closing returns to test robustness. Furthermore, the conclusion of this paper is more reliable because our study includes the world's major oil markets: WTI, Brent, Dubai and Daqing.

Our results indicate that when analysed weekly, all four markets displayed extremely weak-form efficiency with few brief inefficient periods during the past decade, whereas daily oil returns series suggest intermittent and inconsistent efficiency. Daily data suggest that different oil markets will produce different states of efficiency: the Daqing and WTI markets may maintain efficient states, Europe's Brent market will appear inefficient for a long time; no evidence suggests that the UAE's Dubai market will become efficient. We also find that all four markets exhibit asymmetries in return-volatility reactions to different information shocks and that they react more strongly to bad news than to good news. Further, a co-movement phenomenon and volatility spillover effects exist among the oil markets, and the Dubai and Daqing markets exhibit the highest correlation.

The rest of this study is organised as follows. Section 2 briefly introduces our time-varying GAR (p)-TGARCH (m,n) model. Section 3 presents data with summary statistics and empirical results with analysis. Section 4 provides the results of the robustness test. Section 5 proposes some recommendations for the policymakers. Section 6 concludes the study.

2. Methodology: a time-varying GAR (p)-TGARCH (m,n) model

Fama (1970) defines weak-form efficiency as follows: security prices fully reflect the information contained in past price movements, i.e., they do not follow repeating patterns, and it is impossible to trade profitably purely on the basis of historical price information. The essence of weak-form efficiency is that past returns on a market cannot be utilised to predict current returns on the same market. Mathematically, this can be formulated as follows:

$$r_t = b_0 + \sum_{i=1}^{p} b_i r_{t-i} + e_t \tag{1}$$

where r_t denotes the continuously compounded percentage returns on a market. If $b_i = 0$ ($i=1, 2, \ldots, p$), then $r_t = b_0 + e_t$. That is, current returns, r_t, depend only on a constant, b_0, and an error term, e_t. Because b_0 and e_t do not contain any information on past returns, current returns, r_t, cannot be predicted based on past returns r_{t-i} ($i=1, 2, \ldots, p$). Therefore, the market is weak-form efficient. If $b_i \neq 0$, the predictability of current returns can be measured by utilising past returns, that is, the degree to which the market is weak-form inefficient according to Fama's definition.

Eq. (1) is a familiar AR(p) model and provides a useful framework to test the weak-form efficient markets hypothesis (EMH) (i.e., to test $b_1 b_1 = 0$ against $b_1 \neq 0$). Incorporating possible structural change over time, Eq. (1) may be modified as follows:

$$r_t = b_{0t} + \sum_{i=1}^{p} b_{it} r_{t-i} + e_t, \quad e_t \sim N(0, h_t) \tag{2}$$

$$b_{it} = \rho_i b_{it-1} + u_{it}, \quad u_{it} \sim N(0, \sigma_i^2) \tag{3}$$

Eq. (2) is the measurement equation, and Eq. (3) is the transition equation. In the measurement equation, all model parameters, b_{it} ($i=1, 2, \ldots, p$), are allowed to vary at each point of time t. The transition equation then describes the way these parameters evolve. We name this a general auto-regression of order 1 (GAR (1)). An additional advantage of the GAR model is that it can address the problem of heteroskedasticity. Usually, heteroskedasticity in the form of time-varying variance represents the time-varying volatility (risk) of the associated market. To explicitly consider the possible existence of return-volatility, we add the

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