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Detecting method for crude oil price fluctuation mechanism under different periodic time series

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HIGHLIGHTS

- We proposed the concept of autoregressive modes to indicate the fluctuation patterns.
- We constructed transmission networks for studying the fluctuation mechanism.
- There are different fluctuation mechanism under different periodic time series.
- Only a few types of autoregressive modes control the fluctuations in crude oil price.
- There are cluster effects during the fluctuation mechanism of autoregressive modes.

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ABSTRACT

Current existing literatures can characterize the long-term fluctuation of crude oil price time series, however, it is difficult to detect the fluctuation mechanism specifically under short term. Because each fluctuation pattern for one short period contained in a long-term crude oil price time series have dynamic characteristics of diversity; in other words, there exhibit various fluctuation patterns in different short periods and transmit to each other, which reflects the reputedly complicate and chaotic oil market. Thus, we proposed an incorporated method to detect the fluctuation mechanism, which is the evolution of the different fluctuation patterns over time from the complex network perspective. We divided crude oil price time series into segments using sliding time windows, and defined autoregressive modes based on regression models to indicate the fluctuation patterns of each segment. Hence, the transmissions between different types of autoregressive modes over time form a transmission network that contains rich dynamic information. We then capture transmission characteristics of autoregressive modes under different periodic time series through the structure features of the transmission networks. The results indicate that there are various autoregressive modes with significantly different statistical characteristics under different periodic time series. However, only a few types of autoregressive modes and transmission patterns play a major role in the fluctuation mechanism of the crude oil price, and these key autoregressive modes have specific transmission targets. Thus, it is possible to predict the most probable transmission mode from the former mode to a latter one based on the distribution of the transmission probabilities. Moreover, some autoregressive modes often appear together in a certain period and thus form a cluster during the transmission process. All autoregressive modes could be categorized into several clusters, and each cluster then has its own preference to transmit into other clusters. This work not only proposes a distinctive perspective for analyzing the fluctuation mechanism of crude oil price time series, but also provides valuable information regarding different periodic time series for decision makers.

1. Introduction

Because the crude oil price series can characterize the behavior trajectory of the fluctuation of the crude oil market, the fluctuation

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of crude oil price has attracted wide and long-lasting attention from researchers, investors, and policy makers. The crude oil price is a dynamic and nonlinear fluctuation process. The changes of the fluctuation of crude oil price are able to affect the decision making and precautionary behaviors of producers and consumers significantly [1,2]. For example, the spot price of Brent crude oil declined from $115.19 per barrel on June 19, 2014 to $45.13 per barrel on January 13, 2015, representing more than 60% decline within seven months. This shock of the crude oil price caused the producers and investors to rethink the future strategies and decisions. For example, the decline of the crude oil price lead to the decline of the profits of petroleum enterprises, which force some petroleum enterprises to adjust the benchmark yield for appropriate investments.

Currently, a great number of researchers study the fluctuation of crude oil price based on plenty of different methods [3–7]. Especially, researchers focus on studying the structural breaks of the crude oil prices, which means that the crude oil price time series have undergone structural changes due to some unexpected random events [8–12]. When the structural break happen, it will change the long-term trend of the crude oil price and it will make great challenges for the predictability and the stability of the corresponding models. Fan and Xu [13] divide the fluctuations of the crude oil prices into three stages from 2000 to 2009, such as the periods of 'relatively calm market', 'bubble accumulation' and 'global economic crisis'. They found that the main drivers of crude oil price changes and the way of the influence were significantly distinct in different structural periods. Arouri, Lahiani [14] investigated the structural breaks in the conditional volatility of crude oil spot and futures prices by a variety of GARCH-type models. Sun and Shi [15] extended the one-break analysis for multiple breaks test, and the results showed that demonstrated evidence of structural breaks for the crude oil spot prices. They suggested that the energy prices were influenced by long-term economic fundamentals persistently instead of the temporal policy changes. Wen, Gong [16] found significant structural breaks in the volatility of crude oil futures based on sixteen HAR-type volatility models. The results indicated that there were different predictive power in forecasting the one-day, one -week and one -month volatility of crude oil futures under different models.

Moreover, researchers have studied the relationships between crude oil price and other economic indicators. For example, Chiu, Hsu [17] explored the relationships between the crude oil price, corn price and ethanol price based on Vector Autoregressive Model (VAR) and Vector Error Correction Model (VECM). There were structural breaks in crude oil price and there was a unidirectional causality from the crude oil prices to ethanol prices. Shaeri, Adaoglu [18] studied the oil price risk exposure in US over the period of 1983–2015. They identified the structural breaks in the equity returns and they found that the degree of oil price sensitivity differed noticeably across subsectors and over time. Fowowe [19] proved no evidence of a long-term relationship between crude oil prices and agricultural commodity prices in South Africa by the structural breaks cointegration tests. Bondia, Ghosh [20] investigated the relationship between crude oil prices and the stock prices of alternative energy companies. The results indicated that there were two endogenous structural breaks in the cointegration among the crude oil prices and the stock prices.

As mentioned above, some researchers have demonstrated the volatility of crude oil prices based on different types of econometric models, such as autoregressive integrated moving average-generalized autoregressive conditional heteroskedasticity models (ARIMA-GARCH), vector autoregression models (VAR), error correction models (ECM), threshold autoregressive models (TAR) and so on [21–24]. Some researchers have utilized computational intelligence techniques for studying the nonlinear, non-stationary, chaotic and complex nature of crude oil prices [7,25–27]. These computational intelligence algorithms include such as artificial neural network, genetic algorithms, expert system, hybrid intelligent system [28–30]. All aforementioned models can uncover the fluctuation characteristics of the crude oil price over a long period of time by data learning, training or regression fit. Although researchers can identify the structural breaks in the crude oil prices in a long-term periods, the current methods are difficult to reveal the fluctuation mechanism specifically under short term.

To understand the fluctuation mechanism of crude oil price under short term, we should realize that the nonlinearity and instability of crude oil price series are the result of different types of fluctuation patterns in different short time segments, or time windows. For example, Fig. 1 indicates that the Brent crude oil spot price time series is a nonlinear, unsteady fluctuation process because different fluctuation patterns are observed in different periods (between dotted lines). If we divide the entire Brent crude oil spot price time series into smaller segments by sliding time windows, we find that different segments has different fluctuation pattern. And the transmission from one fluctuation pattern to another forms a dynamic evolution process over time.

What is the fluctuation mechanism of crude oil price, scilicet, how the fluctuation patterns evolve over time? Although currently studies can characterize the fluctuation of crude oil prices from the holistic perspective, it is difficult to answer this question. Most of currently studies obtain the features of a time series by the smooth or stationary process of a holistic time series, but such processes may hide the diversity and evolution characteristics of fluctuations in the time series. Obviously, to answer this question, we can obtain more detailed information regarding the fluctuations in the crude oil price, which is helpful to understand crude oil markets.

Thus, in order to understand the fluctuation mechanism of the crude oil price, we should identify the fluctuation pattern firstly. If a long-term crude oil price series is divided into many subseries by time windows, the autoregressive mode of each subseries is different. Thus, the fluctuation patterns of the crude oil price are repeated by autoregressive modes. The evolution of the autoregressive modes over time forms a transmission process that contains rich dynamic information, which is an important issue when studying the transmission of autoregressive modes in the crude oil price. Accordingly, the evolution of the autoregressive modes can facilitates the understanding of the fluctuation mechanism of the crude oil price.

Hence, we can understand the fluctuation mechanism of the crude oil price by studying the transmission process of autoregressive modes. And complex network theory provides an effective approach for exploring the dynamic characteristics of the transmission process. The core idea of complex network theory is to understand the essential characteristics of a system by analyzing the structure of the networks [31,32]. Dynamic information of a time series can be captured through transforming the time series into complex networks [33–37]. These algorithms have been used in the fields of energy economics [38–40]. The results of these studies indicate the feasibility of analyzing time series using complex network theory, and thereby the results provide the foundations for our study. Recently, Wang [41], Chen, Xu [42] researched the fluctuation behavior of the crude oil prices from the complex network perspective that prove the effectiveness of the complex network model in time series analysis for the oil price. They quantified the fluctuation of the crude oil prices based on amplitudes of fluctuation. Although the current studies can describe the transmission process of the fluctuating modes in the crude oil prices, these studies lack of the econometric significance, which cause difficult to reveal the fluctuation mechanism of time series.