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The role of fluctuating modes of autocorrelation in crude oil prices

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HIGHLIGHTS

- We define the fluctuating modes of autocorrelation of time series.
- We transform the fluctuating modes of time series into complex network.
- The node strength of the fluctuating modes follows a power-law distribution.
- Some fluctuating modes play the role of a transmission medium.
- The fluctuation of autocorrelation in oil price time series has periodic feature.

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ABSTRACT

Autocorrelation exists in the crude oil price due to price inertia, the cobweb theorem, model errors, etc. Many researchers have studied the fluctuation of the crude oil price, but few have focused on the autocorrelation fluctuation in crude oil prices. Exploring the fluctuating rules of autocorrelation can aid in understanding the fluctuating mechanism of crude oil prices. To study the role of fluctuating modes of autocorrelation in crude oil prices, which have time series characteristics, this study selected international crude oil spot prices as sample data to employ the methods of statistical physics. The fluctuating modes of autocorrelation were defined by the autocorrelation coefficient, symbolization, and a coarse-graining process. We set the modes as nodes and the transformation between modes as edges; the fluctuating mode weight network of autocorrelation was then built. Thus, the study of autocorrelation fluctuation was transformed to a network study. Then, certain aspects, such as the statistical properties, the "small-world" behavior, and the transmission medium in the network, could be analyzed using complex network theory and analytical methods. The periodicity of the fluctuation was calculated using a spectral analysis method. This study not only describes the fluctuation of the time series more precisely than other methods but also provides ideas for methods of studying the fluctuation of univariate autocorrelations.

1. Introduction

With the development of the "small-world" network model [1], the Newman and Watts network model [2], and the scale-free network model [3], time series can be mapped as networks using different methods in complex network theory.

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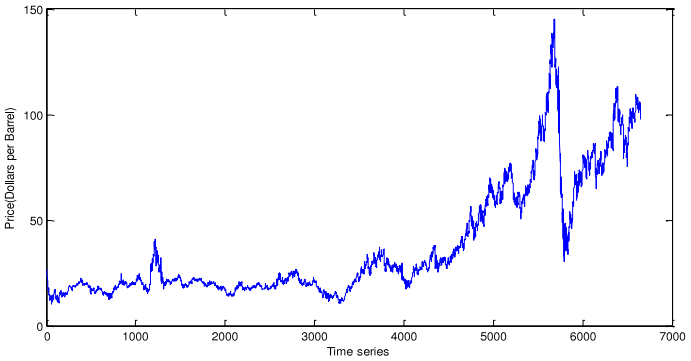

Fig. 1. West Texas Intermediate crude oil spot price series data from January 6, 1986 to May 7, 2012.

Zhang et al. introduced a method to address pseudoperiodic time series and found that the structure of the corresponding network depended on the dynamics of the series [4,5]. Li et al. presented a scheme to extract a multiscale state space network (SSN) from a single-molecule time series [6]. Subsequently, researchers divided the time series into fragments of fixed size. The distinct fragments are the nodes of the network. The links between the nodes are defined by correlation measures [7–9]. These methods are used for measuring the persistence in stationary time series [10].

Lacasa et al. proposed the visibility graph algorithm, which can map all types of time series into networks [11]. In the visibility algorithm, the nodes correspond to the data points of the time series in the same order, and an edge is assigned to connect two nodes if they can "see" each other. Later, the Hurst exponent of fractional Brownian motion was studied using the visibility algorithm [12]. Thus far, the visibility algorithm has been diversely used to investigate stock market indices [13], foreign exchange rates [14], quarterly macroeconomic series [15], and energy dissipation rates [16].

However, most studies at present mainly focus on the numerical values in stationary time series. Studies of the autocorrelation hidden in the time series are especially limited. Specifically, autocorrelation exists in economic time series due to price inertia, the cobweb theorem, model errors, etc. [17–20]. Autocorrelation can be defined as the correlation between members of observations ordered in time series [17]. Autocorrelation also appears in the time series of crude oil prices, and it keeps the crude oil price in a fluctuating state over time [18–20].

The autocorrelation function is an indicator of the degree of autocorrelation. The autocorrelation function can quantify the stationary character of time series, identify its seasonal features, and can be used for forecasting by using regression analysis [21]. Researchers often calculate the autocorrelation coefficients of time series through the autocorrelation function using a holistic perspective [18,19,22]. For example, the autocorrelation coefficient of the overall crude oil prices from 1986 to 2012 is greater than 0.97, which shows a pole-strength positive correlation. Does the degree of autocorrelation always have strong correlations in the perspective of continual fragments with a fixed scale? In our previous study [23], we found that calculating the autocorrelation using a holistic perspective may miss some important information. Because the degree of autocorrelation is unstable in the crude oil price series, even negative correlations exist in some fragments. Moreover, we found that the autocorrelation fluctuates and that fluctuating modes exist in the autocorrelation of the crude oil price time series. The fluctuating modes can display forms of autocorrelation fluctuation in each time series fragment.

In this work, we will investigate the role of the fluctuating modes using complex network theory on the West Texas Intermediate crude oil spot prices from 1986 to 2012 because the crude oil prices are time series which are a form of economic time series. The method used in this study is a time series data analysis technique, which is also suitable for other economic time series. After transferring the fluctuating autocorrelation modes to a network, we will study the statistical properties, the "small-world" behavior, and the transmission medium in the network, using a complex network analytical approach.

2. Materials and methodology

2.1. Materials

The West Texas Intermediate crude oil spot price series data used in the present study come from the U.S. Energy Information Administration (EIA) [24]. The series contains 6645 data points from January 6, 1986 to May 7, 2012 (Fig. 1).

2.2. From fluctuating modes of the autocorrelation to a complex network

To study the fluctuation features of the autocorrelation, we first define the fluctuating modes of the autocorrelation through the autocorrelation coefficient, symbolization, and a coarse-graining process. We then set the fluctuating modes as nodes and the transformations between modes with time as edges. Thus, we establish a complex network model of the fluctuating autocorrelation modes. Furthermore, if the fluctuating modes are divided for the moving time periods, the