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Finding the multipath propagation of multivariable crude oil prices using a wavelet-based network approach

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HIGHLIGHTS

- We introduce a novel wavelet-based network analysis framework that integrates optimization wavelet analysis, GRA, complex network theory and BNA.
- There exist various multiscale phenomena of different dynamic correlations and multipath propagations.
- These leading and intermediary oil prices in the process of the multipath propagation are essential for target-oriented decision making.
- There exists a possible stable community structure of the oil price system in OPEC.

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ABSTRACT

The globalization and regionalization of crude oil trade inevitably give rise to the difference of crude oil prices. The understanding of the pattern of the crude oil prices' mutual propagation is essential for analyzing the development of global oil trade. Previous research has focused mainly on the fuzzy long- or short-term one-to-one propagation of bivariate oil prices, generally ignoring various patterns of periodical multivariate propagation. This study presents a wavelet-based network approach to help uncover the multipath propagation of multivariable crude oil prices in a joint time–frequency period. The weekly oil spot prices of the OPEC member states from June 1999 to March 2011 are adopted as the sample data. First, we used wavelet analysis to find different subseries based on an optimal decomposing scale to describe the periodical feature of the original oil price time series. Second, a complex network model was constructed based on an optimal threshold selection to describe the structural feature of multivariable oil prices. Third, Bayesian network analysis (BNA) was conducted to find the probability causal relationship based on periodical structural features to describe the various patterns of periodical multivariable propagation. Finally, the significance of the leading and intermediary oil prices is discussed. These findings are beneficial for the implementation of periodical target-oriented pricing policies and investment strategies.

1. Introduction

Energy scarcity, the imbalance between the supply and demand of crude oil, the level of commodity speculation and the role of OPEC result in the drastic fluctuation of global oil prices, which play a key role in global commodity trade. With

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the development of the globalization and regionalization of crude oil trade, there are approximately 195 traded crude oil streams in the world according to the International Crude Oil Market Handbook, which inevitably give rise to the difference of crude oil price fluctuations. The diversity of the crude oil price fluctuations of different local representative markets has resulted in a complex system in the global oil market. To gain insight into the global oil market, the propagation of crude oil prices not only provides a way to explain the development of the global oil market bus also assists the implementation of target-oriented pricing policies and investment strategies. The goal of this paper is to identify various patterns of the multipath propagation of multivariable crude oil prices in a joint time–frequency period via a novel study framework that combines different methods of various fields. Foreshadowing our main contributions, our proposed method help uncover the relationship characteristics of a multivariable oil price time series and various patterns of propagation, which can provide a reference for the theory and methods of analysis in the research area of a time series. Our findings regarding the periodical system characteristics among various oil price fluctuations of the OPEC member states represent valuable reference information for the study of the global oil market.

How does one describe the relationship of crude oil prices? To answer this question, the relevant existing studies considered two main approaches: correlation and causality. In particular, the transmission mechanism was proposed to reveal the globalization of various oil price fluctuations [1]. The high interdependency was investigated to explain the regionalization of various oil price fluctuations [2]. More than two sets of oil price time series were used to investigate the global or regional non-stationary and nonlinear volatility characteristics [3]. Regarding the research method, most of the studies used econometric models to investigate the cointegration relationship and the causalities between bivariate oil prices, such as regression analysis [1], the cointegration method [4], and unit root analysis [5]. The copula approach was used to investigate the dependent structure of multivariate oil prices [6]. However, the relationship among various oil prices actually exhibits not only the fuzzy long- or short-term correlation but also certain time–frequency phenomena [7]. Due to the complex mutual influence among various oil prices, a many-to-many relational structure model can more truly reflect the system characteristics of the entire crude oil market.

This paper introduces a novel study framework integrating wavelet analysis, grey relation analysis (GRA), complex network theory and Bayesian network analysis (BNA) to describe and analyze the volatility structure and mutual propagation of a multivariable oil price time series through the statistical properties and community structure analysis of a network model and then considers the leading and intermediary oil prices. In particular, wavelet analysis has been widely used as an effective method to uncover the periodical feature of a time series by using the time–frequency decomposition in a joint time–frequency domain, which can provide richer information about the cyclical modes [8], the structural breaks [9] and the trend analysis [10] to meet the demands of policy makers, speculators and investors. Donald and Andrew proposed Maximal Overlap Discrete Wavelet Transform (MODWT) analysis, which is a far more desirable method in economic and financial fields because of its robustness to the sample size and its selection of a starting point [11,12]. Therefore, we chose the MODWT to decompose the original oil price time series to describe the periodical feature of the original oil price time series.

Subsequently, Deng proposed the GRA method to study the dynamic relationship of the mutual influence among a multivariable time series based on a joint grey system space [13]. Compared with the traditional econometric and financial models, the GRA provides a novel research perspective based on a discovery mechanism of the geometric relationships among the time series data, which have been widely used to uncover interdependent relationships in the economic field because the GRA method not only avoids the common type I or II statistical errors without the process of parameter estimation but is also independent of the sample size, thereby meeting any required statistical distribution [14–19]. Therefore, we chose the GRA to describe the dynamic relationship of the mutual influence among the multivariable oil price time series for the optimization of wavelet decomposition and network analysis.

To determine the structure characteristics among the multivariable oil price time series, complexity science theory is an important and commonly used method for describing system structures, which has been implemented via network or graph theory in existing research. Complex network theory is a very popular method to analyze system phenomena and problems and has been used in a wide range of empirical research studies in various fields, such as biology [20], social sciences [21], and economics [22,23]. In the literature, An used the complex network model to explore the fluctuating rules of a single oil price time series [24]. Huang introduced a hybrid model integrating wavelet analysis and complex network theory to investigate the multiresolution transmission between bivariate oil price time series [7]. In this paper, we used the complex network model based on wavelet decomposition to help uncover the network community characteristics among multivariable oil price time series.

Finally, to determine the pattern of the mutual propagation of various oil prices based on the community structure, we used BNA, which has been widely used to provide information about causality based on Bayesian reasoning [25–27]. Different from the traditional Granger causality test and the existing machine-learning approaches, BNA has several advantages [28]. For example, Bayesian networks can incorporate and convert highly dissimilar types of data into a common probabilistic framework without unnecessary simplification. Additionally, Bayesian networks can readily accommodate missing data and naturally assign a weight to each information source according to its reliability. In contrast, with a black-box system, Bayesian networks represent the conditional probability relationships among information sources. By considering the advantages of various methods, we propose a novel hybrid analysis framework integrating various methods. In the empirical section, we chose the weekly oil spot prices of the OPEC member states from June 1999 to March 2011 as the sample data. Because OPEC is one of the most influential organizations in the global oil market, discovering the periodical characteristics of the internal system structure of OPEC is very representative.