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Fluctuation behavior analysis of international crude oil and gasoline price based on complex network perspective

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HIGHLIGHTS

- The directed and weighted networks of crude price and gasoline price were built.
- The evolution law of the new nodes appeared in the prices networks was obtained.
- The topological structure of price networks was analyzed in different periods.
- The dependency between the two type prices was analyzed based on network similarity.
- The core nodes and the distribution of the time these nodes appeared were identified.

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ABSTRACT

The directed weighted networks of international crude oil and gasoline price were built in the different fluctuation periods. And then the evolution law of the new nodes in the prices networks was analyzed. The results indicated that the cumulative times of the new nodes that appeared in the crude oil and gasoline prices networks were not random but exhibited a high linear growth trend, which revealed the linear characteristics of the accumulation time of abnormal points that appeared in the process of oil price fluctuations. Based on the node strength, the calculation formula of the network similarity between the crude oil and gasoline price networks was designed, and the interdependence between the crude oil and gasoline price fluctuations was calculated, the results indicated that there was a strong interdependence between crude oil and gasoline prices in stable fluctuation periods, but the degree of dependence was significantly reduced in sharp fluctuation periods. The strength of nodes and their strength distribution, weighted clustering coefficient, and average shortest paths of the price network in different periods were calculated. The fluctuation characteristics in different periods were comparatively analyzed. The core fluctuation status and the conversion relationship between them in different periods were revealed. Finally, the important modes of price fluctuations of crude oil and gasoline were identified and the distribution characteristics of the time these modes appeared were studied.

1. Introduction

The evolution of energy prices contains a variety of information in the energy market. Energy price plays an important role in national economic development, energy intensity, carbon emissions and so on. The volatility of energy prices not only affected by the basic supply and demand in the market but also by many other factors, such as emergency, speculation, and market psychology, so the evolution processes of energy prices have great uncertainty. Therefore, how to explore the mechanism of fluctuations of energy prices is becoming the hot topic of academic research.

In recent years, the research of the issue of energy price has attracted a great deal of attention from various fields of researchers. Ji and Fan [1] measured the influence of the crude oil market on non-energy commodity markets before and after the 2008 financial crisis. Wang and Tian [2] proposed a novel dynamic system model of energy price–energy supply–economic growth based on the cau-

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sal relationships among energy price, energy supply and economic growth during a given economic period. They established a network structure of mutual transmission between different elements and went on to establish a new dynamic systematic model of energy price–supply–economic growth. Koirala et al. [3] investigated the interdependence between agricultural commodity futures prices and energy futures prices, and the results showed that agricultural commodity and energy future prices were positively correlated. Dias et al. [4] made a joint analysis of the price of oil, natural gas, and electricity in U.S. markets using a multi-conversion model that captured the typical facts of energy prices. Nazlioglu et al. [5] examined whether there was a volatility transmission between oil prices and financial stress by means of the volatility spillover test. Atil et al. [6] used the nonlinear autoregressive distributed lags (NARDL) model to examine the pass-through of crude oil prices into gasoline and natural gas prices. Coleman [7] analyzed real oil prices during 1984–2007 using a monthly dataset of fundamental and market parameters. Chai et al. [8] obtained the core factors, built an oil price system VAR model, which used demand, supply, price, and inventory as endogenous variables, and China's net imports as well as dollar index as exogenous variables based on the PATH-ANALYSIS model. Zhang et al. [9] empirically investigated the functions of price discovery and risk transfer in crude oil and gasoline futures markets using multiple econometric models. Narayan et al. [10] considered five different forms of oil futures contracts and examined price fluctuation clustering. Chiroma et al. [11] proposed an alternative approach based on a genetic algorithm and neural network (GA–NN) for the prediction of the West Texas Intermediate (WTI) crude oil price. To sum up, a large number of scholars at home and abroad adopted a variety of methods for the systematic research of the related issues of energy price system. They established many practical models to research the conduction relationships between energy price and its related factors, and to predict of the trend and volatility of energy prices in the future, etc. However, the traditional approach to the problem of energy price volatility research mainly was to establish a variety of econometric model and explain the reason and mechanism of oil price fluctuations, but the energy price system is essentially a complex nonlinear and non-stationary system. Traditional approaches rarely touched on the questions of how to construct a complex network analysis model of energy price and how to explore the complex characteristics of energy price system deeply.

Complex network is a hot research topic in recent years, the main idea of which is to regard the link between the real parts of the system as a complex network, in order to better understand the essence of reality system. With the discoveries of the scale-free network model [12,13], the small-world network [14], the Newman and Watts network [15], and the random network model [16], complex network is applied in more and more fields, providing us a new perspective and approach to the studies of complexity problems.

Recently, complex network theory has been applied to solve problems in the fields of energy economy with considerable achievements. Chen et al. [17] proposed the international oil price network and analyzed the dynamic properties of the network. An et al. [18] studied the role of fluctuating autocorrelation modes in the crude oil price time series. An et al. [19] established a trading-based network model of international crude oil to study the relationship between countries with common trade partners. Hao et al. [20] built a global fossil energy exergy flow network with countries as nodes, the international exergy flows as edges and the exergy of each flow as the weight of the edges, and analyzed the distribution of countries, the overall structure, major countries and major exergy flow paths of the network from 1996 to 2012. Gao et al. [21] studied the transmission characteristics of fluctuant patterns of the forex burden based on international crude oil prices. Zhong et al. [22] set up unweighted and weighted oil trade network models based on complex network theory using data from 2002 to 2011 to study the evolution of trade communities in the international oil trade network. Huang et al. [23] introduced an approach to the multiscale transmission characteristics of the correlation modes between bivariate time series. Gao et al. [24] built the international fossil energy trade multilayer network (ETMN), and studied the evolutionary characteristics of networks during 2002–2013. An et al. [25] designed a complex network approach to the dynamics of the co-movement between crude oil futures and spot prices.

Based on the above analysis, there are three main references to study the energy price issue based on the complex network theory in the previous literature, that is, Refs. [17,18,25]. Only Ref. [17] directly uses the energy price data to construct the network. The existing literature has provided a solid empirical investigation and a good reference for understanding the evolution of the energy price network, but some problems still need to be further examined. For instance, (1) the previous literature only used three states i.e. {increase, stable, decline} to describe the energy price fluctuations, which leads to the loss of complexity information of energy price fluctuations. (2) Previous studies lack of the research of network node evolution over time and considerations about such questions as whether the advent of the new node is regular, when an important node in network is to appear, and so on. (3) It is well known that the energy price fluctuations have different statuses at different times. Previous studies haven't done contrast analysis of what distinctions and connections the topology structure of the energy price network in different periods. (4) Different energy prices volatility have the strong dependency in the process. Previous studies haven't touched upon the question of whether the above-mentioned dependency can be measured through the similarity of the network.

In this paper, we construct the crude oil and gasoline price directed and weighted complex networks based on the novel framework in different periods, and explore the topological structure of the networks. Four main novel contributions in our studies are as follows: (1) we convert the crude oil and gasoline price volatility sequences into the characters composed by five symbols $\{R, r, e, d, D\}$, which is different from the previous literature converting the sequences into three symbols $\{R, e, D\}$. Our conversion can better reflect complexity of energy price fluctuations. (2) Based on the probability of different characters appearing in the price fluctuation sequences of crude oil futures and gasoline, we construct the crude oil and gasoline price network in different periods and conduct comparative analysis accordingly, which has never been achieved in previous studies. For the first time, we verified the crude oil and gasoline price networks are assortative networks. (3) We take the time factor into consideration in building the network and provide the evolution law of the nodes changing in time. Not only the important nodes are identified, but the distribution characteristics of the time when the important nodes appear are also studied. (4) We design the calculation formula to measure the similarity between the crude oil and gasoline price network based on the strength of same nodes. And we analyze the interdependence between the crude oil and gasoline price volatility based on the viewpoint of the similarity of the network.

The main idea of this paper is to build a directed weighted network of the prices of crude oil and gasoline in different periods, to comparatively analyze the topological structure of the network of the prices of crude oil and gasoline. The purpose is to find the evolution law of the network of the prices of crude oil and gasoline and the main characteristics in different periods. The research framework is shown in Fig. 1.

From the research framework of this paper, our research is divided into three levels. First of all, we convert crude oil and gaso-