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A complex network perspective on features and evolution of world crude oil trade

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Abstract

In this paper, a directed world crude oil trade network is constructed to learn the topological structure properties. We find the oil trade network follows power-law distribution. This is further confirmed by degree correlation coefficient, which implies the crude oil network is disassortative. The relationship of betweenness centrality value and node degree is analyzed. The result shows countries with high betweenness centrality, are also with high degree. In the whole sample time interval, the reciprocity value shows an increasing trend. A growing number of countries have expanded their bilateral trade relations. At last, some suggestions are given according to the results.

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Keywords: World crude oil trade; Complex network; Structural feature and evolution

1. Introduction

The world curde oil trade is subject to the unbalance distribution of crude oil production and consumption. As an important factor affecting economic development and people's living, global oil trade patterns are increasingly concerned by researchers and policy makers [1-3].

We are surrounded by networks, almost all complex systems may be abstracted as complex networks. The complex network consists of a mass of nodes and the connections between nodes are seriously complex. Network analysis method is widely used to uncover structural feature of complex systems, with application in many fields such as scientific collaboration, biology, food web, transportation, economics, social networks, and environmental network [3-9]. A trading-based network model of international crude oil was established by An et al. to study the relationship between countries with common trade partners

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[3]. Ref. [4] built a network model using ecological network analysis to holistically evaluate the security of the crude oil supply in China. Ji et. al. identified the global oil trade patterns using complex network theory, discovering that the global oil export core network displays a scale-free behavior [5]. Alexandre et al. predicted the future evolution of international trade ntwork through link prediction algorithms [6]. Zhang et al. studied the competition among oil importers using complex network theory, combined with several alternative measure of competition intensity, to analyze the evolution of the pattern of oil-trading completion [7]. Zhong et al. studied the evolution of communities of the international oil trade network by setting up un-weighted and weighted oil trade network models based on complex network theory [8]. Gao et al. studied the features and evolution of international fossil energy trade relationships by using a weighted multilayer network analysis [9].

In this paper, the world crude oil trade network is constructed with complex network theory. We detailedly analyze the topological structure and evolutionary characterictics of crude oil trade patterns. The reminder of this paper is organized as follows: Section 2 introduces the data and method. Section 3 is empirical analysis for global crude oil trade network. Section 4 is provides concluding remarks.

2. Data and method

2.1 Data

We built a network model using the data on international crude oil trade downloaded from UN *Comtrade*, which contains all export and import flows among 190 countries in the world. The name of the commodity is “crude petroleum oils” (the HS code is 270900). We selected the annual oil trade for all these countries during 2001-2013. Data from one year form a single complex network. Therefore, there are 13 networks in time series in our model.

2.2 Method

Complex network theory is a powerful system-oriented modeling technique used to examine the structure, function and flow of crude oil in trading system. The directed global crude oil trade network model is constructed, where the nations are the nodes, and the crude oil trade relationships between the nations are considered as the edges. There also exist two types of crude oil trading-based networks. One is importing-based network, and the other is exporting-based network. An example network from 2013 is shown in Fig. 1.

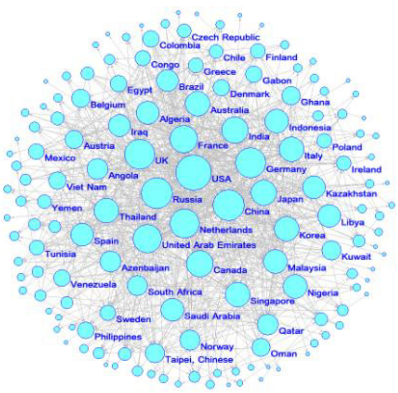

Fig. 1 The complex network of the international crude oil trade in 2013.

The overall features of world crude oil trade network can reflect the trade patterns directly. Thus we use four specific indicators here for analyzing the structural characteristics of crude oil trade network: degree and degree distribution, betweenness centrality, degree correlation and reciprocity.

(1) Degree and degree distribution

The problem of identifying whether the nodes play a key role is one of the main topics in the traditional analysis of complex networks. One of the centrality measures is degree of nodes [10]. The degree k_i of node (nation) i denotes the number of connections or edges the node has to other nodes. Nodes have two different degrees, the indegree k_{in}, which is the number of incoming edges, and the out-degree k_{out}, which is the outgoing edges. The degree distribution $P(k)$ is defined to be the fraction of nodes in the network with degree $k = k_{in} + k_{out}$. Thus if there are n nodes in total in a network and n_k of them have degree k, we have

$$P(k) = \frac{n_k}{n}. \tag{1}$$

(2) Betweenness centrality

The betweenness centrality is a metric that indicates the relative importance of a node in the connectivity of a network. In a graph with V vertices, the betweenness centrality of a vertex v is defined according to Freeman [11] as:

$$g(v) = \sum_{s \neq t \neq v} \frac{\sigma_{st}(v)}{\sigma_{st}}, \tag{2}$$

where σ_{st} is the number of shortest paths between each vertex $s \in V$ and $t \in V$, and σ_{st} is the number of shortest paths passing through vertex v.

(3) Degree correlation

Many real networks always contain different types of nodes, edge connection between vertex probability often depends on the vertex type. Newman defined a measure of assortative mixing for networks, the assortativity coefficient [12]:

$$r = \frac{M^{-1}\sum_i j_i k_i - [M^{-1}\sum_i \frac{1}{2}(j_i + k_i)]^2}{M^{-1}\sum_i \frac{1}{2}(j_i^2 + k_i^2) - [M^{-1}\sum_i \frac{1}{2}(j_i + k_i)]^2}, \tag{3}$$

where M is the number of links in the network, j_i, k_i are the degrees of the nodes at the end of the i -th edge, with $i = 1, 2, ..., M$. When $r > 0$, the network is assortative, which means the node with higher degree tends to connect to node with higher degree. When $r < 0$, the network is disassortative, which means a node with higher degree has higher probability of being connected to node with lower degree.

(4) Reciprocity

Reciprocity is defined as the correlation coefficient between the entries of the adjacency matrix of a directed network ($a_{ij}=1$ if a link from i to j is there, and $a_{ij}=0$ if not) [13]:

$$R=\frac{\sum_{i\neq j}(a_{ij}-\overline{a})(a_{ji}-\overline{a})}{\sum_{i\neq j}(a_{ij}-\overline{a})^2}, \tag{4}$$

where the average value $\overline{a}=\frac{\sum\limits_{i\neq j}a_{ij}}{N(N-1)}$ (link density) measures the ratio of observed to possible links. If $R>0$, the crude oil trade network is reciprocal; otherwise, it is antireciprocal. The steep increase $R\to 1$ signals that the world economy is rapidly evolving towards an "ordered phase" where all trade relationships are bidirectional.

3. Results and analysis

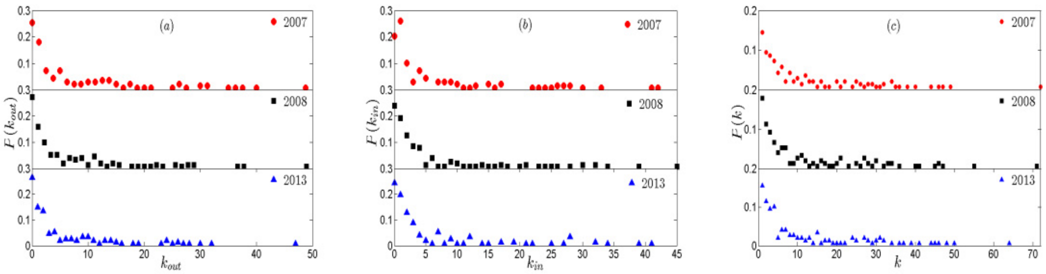

Fig. 2 The relationship of degree distribution and degree in 2007, 2008 and 2013.

We take the results of 2007, 2008 and 2013 as examples and describe the degree distributions. The relationships between outdegree distribution and outdegree, indegree distribution and indegree, degree distribution and degree, reveal "long tail" effect, which indicates that these models follow power-law distributions, as shown in Fig.2. It means that in the three types of networks, the new countries prefer to establish energy trade relationships with the core countries.

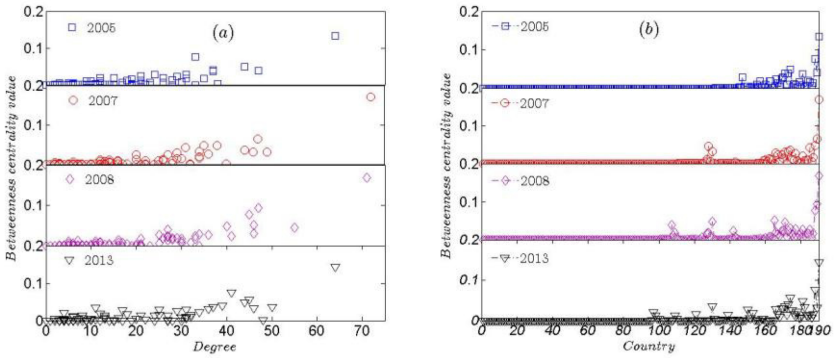

Fig. 3 Scatter plots of betweenness centrality value of the world countries, against vertex degree (left) and country (right).

Another node centrality measure is betweenness centrality. In Fig. 3(a), the horizontal axis indicates the degree of node in 2005, 2007, 2008, 2013, and the vertical axis represents the value of the betweenness centrality. For international crude oil trade network, as the node degree increases, the betweenness centrality also increases. As shown in Fig. 3(a), only the slope of the line formed by the betweenness centrality of nodes with high degree is relatively large, which means nodes with high degree are of a strong intermediary nature. We further find countries with higher betweenness centrality values are always the same though in different years, such as the United States of America, United Arab Emirates, United Kingdom, Russia, Germany, China, Netherland etc, which are always with higher degree, as shown in Fig. 3(b).

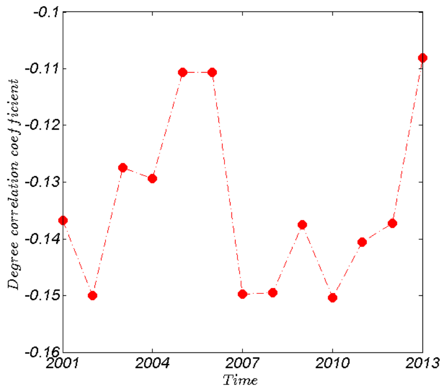

Fig. 4 The evolution of degree correlation coefficient of crude oil trade network depending on time.

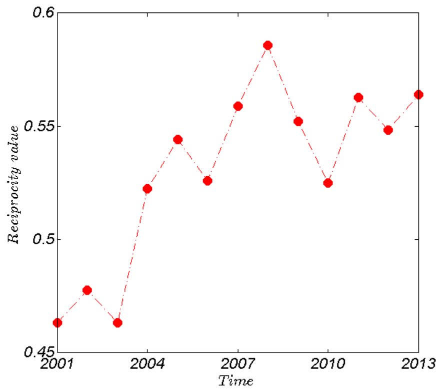

Fig. 5 Reciprocity of global oil trade network from 2001 to 2013.

Fig. 4 shows the evolution of degree correlation coefficient, which is obtained based on a set of network models for each year during 2001-2013. We find $r < 0$ in the whole sample period. It means the network is disassortative. Small countries tend to trade with major trading countries to form economic cooperation organization with oil trading powers as the core. After 2010 the line of the degree correlation coefficient grows steadily, showing that one country would prefer to trade with many countries and regions, and adopt a strategy of diversification in oil supply. Fig. 5 shows the reciprocity evolution of world crude oil trade network depending on time. The reciprocity value increases from 0.463 in 2001 to 0.564 in 2013. This indicates that the reciprocity of the whole network is increasing, and the two-way trade relations are carried out in more and more countries.

4. Conclusions and Discussions

In this paper, we construct a directed global crude oil trade network. The topological structure and evolutionary features are detailedly analyzed. We find the three types of networks follow power-law distributions, which means most of countries have few trading nations while only a minority has a large number of trading partners. It is further illustrated by the evolution of degree correlation coefficient, which shows the crude oil trade network presents disassortative characteristic. Furthermore, we find for global crude oil trade network, nodes with large betweenness centrality, are always with large degree. It shows the few countries have most trading partners, and simultaneously they are seen as important transit hubs. Besides, from the analysis of reciprocity, with more countries participate in the world crude oil trade system, their statuses are more orderly, and the coexistence of economic globalization and local integration is strengthened.

Therefore, we put forward the following suggestions: first, the trading strategy of major importers and exporters should be optimized to ensure the security of oil supply and demand. For example, oil importers can reduce their dependency on certain exporters and import diversifying energy sources from more countries in order to weaken the heterogeneity. Second, more crude oil transit centers should be encouraged to build to adjust the transfer of oil through the whole network.

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Biography Dr. Ruijin Du works in Jiangsu University. Her current work involves modeling and analysis of energy supply-demand system, complex network theory and application, etc. She has published more than 20 academic papers.