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Identification of global oil trade patterns: An empirical research based on complex network theory

Qiang Ji, Hai-Ying Zhang, Ying Fan *

Center for Energy & Environmental Policy Research, Institute of Policy and Management, Chinese Academy of Sciences, Beijing 100190, China

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ABSTRACT

The Global oil trade pattern becomes increasingly complex, which has become one of the most important factors affecting every country's energy strategy and economic development. In this paper, a global oil trade core network is constructed to analyze the overall features, regional characteristics and stability of the oil trade using complex network theory. The results indicate that the global oil export core network displays a scale-free behaviour, in which the trade position of nodes presents obvious heterogeneity and the 'hub nodes' play a 'bridge' role in the formation process of the trade network. The current global oil trade network can be divided into three trading blocs, including the 'South America-West Africa-North America' trading bloc, the 'Middle East–Asian–Pacific region' trading bloc, and 'the former Soviet Union–North Africa–Europe' trading bloc. Geopolitics and diplomatic relations are the two main reasons for this regional oil trade structure. Moreover, the global oil trade network presents a 'robust but yet fragile' characteristic, and the impacts of trade interruption always tend to spread throughout the whole network even if the occurrence of export disruptions is localised.

1. Introduction

Since the 20th century, due to the unbalance in the distribution of oil resources and the rapid growth in the demand for oil, the world oil trade has grown quickly. Total global oil imports rose 74% from 1990 to 2011. The share of world oil imports in oil consumption reached 62% in 2011. This indicates that more than 60% of the global oil consumption is met by imports, which play a core role in supporting the consumers' oil demand. Therefore, the oil trade has become an important factor affecting oil-consuming countries' energy strategies and economic development. However, along with the excess consumption of oil resources and limited global oil capacity expansion, oil production areas become more and more concentrated, and the supply and demand situation of oil resources becomes ever more severe. On the one hand, the scale of global trade will continue rising since more and more countries are involved in the competitive arena of global oil trade, and the contradiction between the supply and demand will be much more prominent. On the other hand, global oil trade patterns become increasingly complex owing to the impacts of geopolitical risk and oil price fluctuations. Obviously, global oil trade patterns result from games between oil-producing and oil-consuming countries on a global scale. Within intricate oil trade relationships, how to identify the overall and regional characteristics of oil trade patterns and recognize the changes of trade dependence and trade positions between oil-producing and oil-consuming countries is of great importance for every country to master the oil trade rules, to develop export–import strategies and to jointly maintain the stability of oil trade.

At present, most researches on oil trade patterns are qualitative. Christy [1] analyzed changes in global oil trade patterns caused by increased Russian oil exports and considered that the increase of Russian oil exports has improved Russia's position in the world crude oil market and decreased oil-importing countries' dependence on the Middle East. Balat [2] studied the Middle East's oil potential and position in the oil market from the aspects of oil production, foreign trade structure, etc. Shan [3] analyzed the changes in world oil trade patterns over the past ten years and forecasted that the world trade structure and flow would evolve further and the Asian-Pacific region would become an important part of the new world trade patterns.

Actually, oil trade flows reflect the relationships among countries, which can form a network where the countries are taken as the nodes and the trade relationships as the edges. Thus, the development of complex network theory has offered an effective tool for the quantitative analysis of oil trade patterns by identifying the characteristics of the trade network. To date, complex network theory has been well-applied in the study of world trade network. Wilhite [4], Serrano and Boguna [5], and Li [6] discovered the world

* Corresponding author. Tel.: +86 10 62542627.
E-mail address: yfan@casipm.ac.cn (Y. Fan).

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trade network displayed the typical properties of complex networks, namely scale-free degree distribution and small-world property. Fagiolo et al. [7] and [8] employed a weighted network analysis to study the empirical properties of the world trade web. Garlaschelli and Loffredo [9] studied the properties of the world trade web as a directed and evolving network and confirmed that the network's topology displayed a peculiar dependence on the GDP of world countries. Benedictis and Tajoli [10] showed that the world trade network has indeed changed over the past decades. The trading system has become more intensely interconnected, while the heterogeneity among countries increased and trade policies played a role in shaping the trade network. Ermann and Shepelyansky [11] applied ecological analysis to the description of world trade, and found that countries and trade products were analogous to plants and pollinators, and that the whole trade network was characterized by a high nestedness typical of ecological networks. While, few studies focus on the oil trade network except for Sun et al. [12] and Xu [13]. However, both these two studies just identified the structure of the oil trade network at the global level simply without exploring the oil trade patterns comprehensively.

This paper applies complex network theory to the quantitative analysis of overall features, regional characteristics and stability of oil trade at 'global-regional- national' levels, which is attempt to identify the global oil trade pattern from different perspectives. The main contributions are as follows: (1) Taking into account the difference of trade relationships between countries, a global oil trade core network is built to focus on the relationships with important influences, showing the core characteristics of oil trade network. (2) The systematic analytical framework of the oil trade core network based on different research hierarchies is constructed to comprehensively understand the structural characteristics of global oil trade patterns and reveal the complex characteristics and operation laws of the current oil trade network objectively by using complex network theory. (3) As oil trade is closely related to energy security, on the basis of identification of current oil trade patterns, corresponding policies and suggestions to maintain stability of oil trade and ensure energy security of each country are put forward.

2. The construction of the global oil trade core network

The trade flow of oil resources among countries forms the global oil trade network. According to complex network theory, the oil trade directed network is represented by a set $G = (V,E)$, where the trade countries $V = \{v_1, v_2, \ldots, v_N\}$ in the trade system are taken as the network nodes and the trade flow set E as the network edges. The network structure can be represented by the adjacent matrix $e_{ij} = 1$ if oil exports from country v_i to country v_j, otherwise $e_{ij} = 0$. In this paper, the differences in trade relationships among different countries are taken into account, and then the trade relationships are filtered to retain those network edges with important trade relationships. In this way, the global oil trade core network is constructed to better highlight the countries and relationships with significant trade positions.

In this paper, export intensity is used as the filtering criteria. The definition of 'export intensity' is as follows [14]:

$$XTI(i,j) = \frac{X_{ij}/X_i}{M_j/M_w} \tag{1}$$

where $XTI(i,j)$ is the export intensity between country v_i and country v_j; X_{ij} is the export volume from country v_i to country v_j; X_i is the total export volume of country v_i. M_j is the total import volume of country v_j; M_w is the world total import volume.

Export intensity is a measurement of the relationship closeness between two trade countries. The statistic indicates whether or not a country exports more (as a percentage) to a given destination than the world does on average. An export intensity value greater than 1 implies a country exports more to the destination than the world does on average, reflecting an 'intense' trade relationship; while the value less than 1 indicates a 'weak' relationship. In theory, the export intensity of country v_i is equal to the import intensity of country v_j for the same trade partners (country v_i exports oil to country v_j). Thus, the oil trade core network structure is expressed as follows:

$$a_{ij} = e_{ij} \times \begin{cases} 1 & XTI(i,j) > 1 \\ 0 & XTI(i,j) < 1 \end{cases} \tag{2}$$

3. Research framework and measure indexes of oil trade core network

In this paper, oil trade patterns are analyzed according to three research contents, including overall features, regional characteristics and stability of oil trade. To deal with the practical problems of the oil trade core network, we select different research levels and measure indexes. The detailed research framework is shown in Fig. 1.

3.1. The overall features of trade network

The overall features of the trade network are the most direct reflection of trade patterns at the global level. The trade network is the carrier of world trade and is also fundamental to the smooth running of it. And meanwhile, the trade stability depends on the trade network's structure to a large extent. Thus, identifying the structure characteristics of trade network is an important part of detecting oil trade pattern situations. Two specific indicators are applied for the identification of the features: degree and degree distribution, clustering coefficient.

3.1.1. Degree and degree distribution

In the oil trade core network, the degree of a trade node is measured by the number of its trade partners with important trade relationships. Intuitively, the larger the country's degree is, the more trade influence it has, which plays an important supporting role in the stability of the trade network. If a network is directed, the nodes have two different degrees, the in-degree, which is the number of incoming edges, and the out-degree, which is the number of outgoing edges. The formulas are as follows:

$$\text{in-degree}: \ k_j^{in} = \sum_{i=1}^{v_N} a_{ij} \quad j = v_1, v_2, \ldots, v_N \tag{3}$$

$$\text{out-degree}: \ k_i^{out} = \sum_{j=1}^{v_N} a_{ij} \quad i = v_1, v_2, \ldots, v_N \tag{4}$$

The degree distribution of a network is used to describe the distributing characteristic of the number of connections the node has and to study the node heterogeneity. The formula is as follows:

$$P(k) = N_k/N \tag{5}$$

where N_k is the number of nodes with degree k; N is the total number of nodes in the network.

As for random networks, the degree distribution follows a Poisson distribution, which indicates that the nodes have the same degree and displays homogeneous characteristic. While, if the degree distribution follows a power law $p(k) = k^{-r}$ indicates that the nodes have obvious heterogeneity, and the importance varies from node to node, with few 'hub nodes' having high degrees, but many 'secondary nodes' having low degrees. Such networks are called scale-free networks [15].

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