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# Global Trade Pattern of Crude Oil and Petroleum Products: Analysis Based on Complex Network

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**Abstract:** Crude oil and petroleum products are important in the economic development. They are widely traded all over the world. It has great significance for policy makers to quantitatively understand the global pattern of the international trade of crude oil and petroleum products. This study uses complex network method to analyse the global pattern of international trade of crude oil and petroleum products. The average trade volumes, the network connectivity, the network partition and major countries in the communities are analysed to reveal the global pattern of the two types of networks. The findings are: (1) The connectivity of the network of petroleum products is higher than the connectivity of the network of crude oil and the partition of the network of petroleum products is greater than that of the network of crude oil. (2) The financial crisis in 2008 had obvious impact; however, the impact has opposite effects on the global trade pattern of crude oil and petroleum products. (3) The geographical factor is becoming more obvious in the trade pattern of crude oil, but not so obvious in the trade pattern of petroleum products.

## 1. Introduction

Crude oil and petroleum products are widely traded all over the world. The trade relationships among the countries are not evenly distributed. Some countries are closely related, while some others are loosely related, thus form a global pattern of international trade. Researchers found that the international trade network is clustering into communities (or groups) according to factors such as geography or GDP rather than by regional-trade agreements [1, 2]. It is important to quantitatively reveal the global pattern [3], and discuss what drives the formation of global oil trade patterns [4, 5] for the policy makers.

Complex network method is a good way in analyzing international trade [6]. In previous studies, Fagiolo et al. studied the evolution of the world trade web by network analysis [7, 8]. Duan et al. carried out the research on the measurement and evolution model of world trade networks [9]. Ji et al. applied a global oil trade core network to analyze the overall features, regional characteristics, and stability of the oil trade [10]. Guan et al. estimated the potential trade links in the international crude oil trade [11]. The competition relationship between countries in the international crude oil trade network was also studied [12, 13]. These studies are good applications of complex network methods on the study of international trade of crude oil.



Community analysis can reveal the global pattern of international trade [14, 15]. For example, Tzekina et al. studied the evolution of community structure in the world trade web [16]. Zhong et al. applied weighted and unweighted complex network analysis to study the evolution of communities in the international oil trade [17]. Ji et al. identified the global oil trade patterns by an empirical research based on complex network theory [10]. Yang et al. found it is a small and flat world by complex network analysis of international trade in crude oil [18]. Normalized Mutual Information (NMI) was used to measure the global pattern of the trade communities of fossil fuel [19]. These studies revealed the international trade pattern of crude oil by community analysis of complex network method.

## 2. Data and Model

The data source of this study is the database of *UN Comtrade*, which contains all export and import flows of crude oil and petroleum products among more than 200 countries and regions in the world. The HS code of crude oil is 2709 and the HS code of petroleum products is 2710. The names of the commodities are “Petroleum oils, oils from bituminous minerals, crude” and “Oils petroleum, bituminous, distillates, except crude”. This study used the annual data from 2006 to 2015, and the trade volume is measured by US \$.

The complex network model  $G = (V, E)$  contains node  $V$  and edge  $E$ .  $V = \{v_i: i = 1, 2, \dots, n\}$ ,  $E = \{e_i: i = 1, 2, \dots, m\}$ ,  $n$  is the number of nodes, and  $m$  is the number of edges. The matrix the model is as follows [19]:

$$G = (V, E) = \begin{bmatrix} 0 & w_{1,2} & \cdots & w_{1,n} \\ w_{2,1} & 0 & \cdots & w_{2,n} \\ \vdots & \vdots & \ddots & \vdots \\ w_{n,1} & w_{n,2} & \cdots & 0 \end{bmatrix} \quad (1)$$

In the network model of international trade, the nodes are countries, and the edges are the trade links among these countries which are with direction. The weights of the edges are the trade volumes (\$).

The clustering coefficient of a country is the possibility of a trade relationship between the country's trading partners in the network. It reflects the connectivity between the country's trading partners. If a country's trading partners are closely related, then the country's clustering coefficient is high; on the contrary, if the relationship between a country's trading partners is loose, then the country's clustering coefficient is low. The clustering coefficient  $C_i$  of node  $i$  is calculated as follows:

$$C_i = \frac{n_i}{k_i(k_i-1)} \quad (2)$$

where  $n_i$  is the number of edges between adjacent nodes of node  $i$ , and  $k_i$  is the degree of node  $i$ . The average clustering coefficient of all the countries in the network reflects the connectivity of the whole network.

This study introduces a grouping algorithm based on modularity to group the international trade network [20]. The modularity is used to measure the degree of division of the network indicators. The greater the modularity is, the more obvious the division of the network, the smaller the modularity is, the less obvious the division of the network. The value of modularity is between -1 and 1. The formula of modularity is as follows. :

$$Q = \frac{1}{2m} \sum_{i,j} \left[ w_{i,j} - \frac{A_i A_j}{2m} \right] \delta(c_i, c_j) \quad (3)$$

where  $w_{i,j}$  is the weight of the edge between node  $i$  and node  $j$ ,  $A_i = \sum_j w_{i,j}$  is the sum of the weights of all the edges of node  $i$ ,  $A_j = \sum_i w_{j,i}$  is the sum of the weights of all the edges of node  $j$ ,  $m = \frac{1}{2} \sum_{i,j} w_{i,j}$ ,  $c_i$  is the community which contends node  $i$ ,  $c_j$  is the community which contends node  $j$ . If node  $i$  and node  $j$  is in the same community,  $c_i = c_j$ , and  $\delta(c_i, c_j) = 1$ , otherwise  $\delta(c_i, c_j) = 0$ .

The algorithm is divided into two steps:

Step 1: Initialize the network for  $n$  groups, and each node  $i$  is an independent group. The node  $i$  joins all the connected groups  $j$  of node  $i$ , and if the  $\Delta Q$  value is positive, the node  $i$  joins the group  $j$  which makes the maximum  $\Delta Q$ ; and if  $\Delta Q$  is negative, then the node  $i$  remains in the original group. Do

this step for all nodes in the network until the modularity value is no longer improved. Modularity increments  $\Delta Q$  are calculated as:

$$\Delta Q = \left[ \frac{\sum C_{in} + A_{i,in}}{2m} - \left( \frac{\sum \text{tot} + A_i}{2m} \right)^2 \right] - \left[ \frac{\sum \text{in}}{2m} - \left( \frac{\sum \text{tot}}{2m} \right)^2 - \left( \frac{A_i}{2m} \right)^2 \right] \quad (4)$$

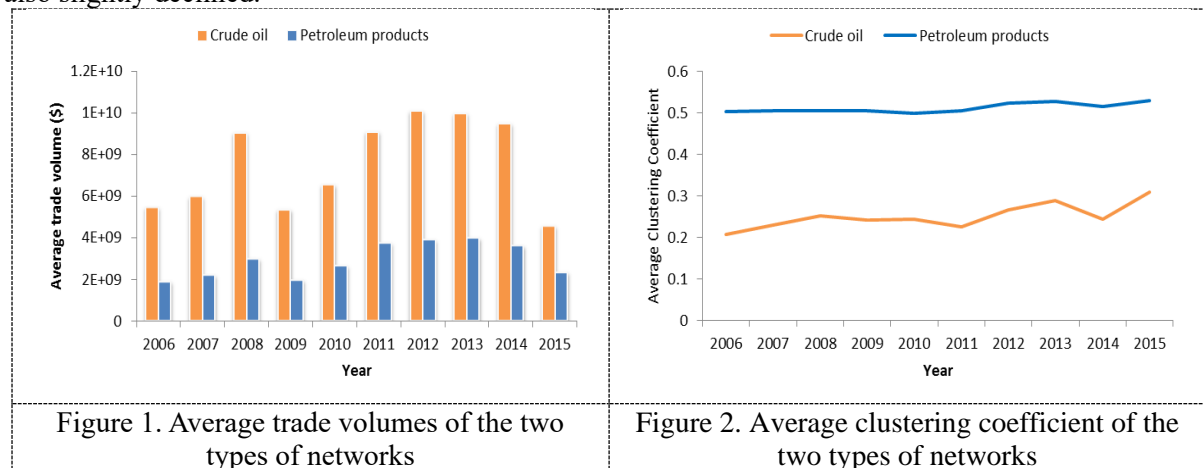
where  $\sum C_{in}$  is the sum of the weights of the edges between all the nodes in group  $C$ ,  $\sum \text{tot}$  is the sum of the weights of all nodes in group  $C$  and all nodes in the network,  $A_i$  is the sum of the weights of all the edges of node  $i$ ,  $A_{i,in}$  is the sum of the weights of all the edges between node  $i$  and nodes in group  $C$ ,  $m$  is the sum of the weights of all edges in the network.

Step 2: The group obtained in step 1 is set as a new node. The weight of the edges between the new nodes is the sum of the weights of the edges between the nodes in the corresponding two groups. The edges of nodes in the same group are self-loops in the new network.

Once the new network is built, step 1 is reapplied to the new network, and the process is repeated until there is no more improvement and the maximum value of the modularity is obtained.

### 3. Analysis and Results

The average trade volumes of all the countries in both trade networks are shown in Figure 1. The trade volume of crude oil is more than two times of the trade volume of petroleum products. The evolution trends of both volumes are similar. An obvious drop occurred in 2009, and since 2014, the trade volume also slightly declined.



The average clustering coefficients of all the countries in both trade networks are shown in Figure 2. The average clustering coefficients reflect the connectivity of the whole network. The connectivity of the network of petroleum products is higher than the connectivity of the network of crude oil. This result indicates that countries in the network of petroleum products are more related to each other.

The numbers of groups in the two types of networks are shown in Figure 3. There are more groups in the network of petroleum products than that in the network of crude oil. In most of the year, there are 7 groups in the network of petroleum products, and in 2009 and 2010 there are 9 groups. In most of the year, there are 5 groups in the network of crude oil, and in 2008 and 2009 there are 4 groups.

The modularities of the two types of networks are shown in Figure 4. The modularity of the network of petroleum products is greater than that of the network of crude oil. Both of them are decreasing during the whole period. The decrease of petroleum products is more obvious. At the same time, they have opposite fluctuating tendency. In 2009, the modularity of the network of petroleum products was decreasing and the modularity of the network of crude oil was increasing.

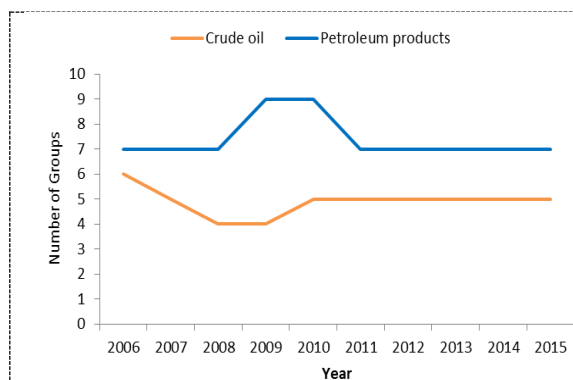


Figure 3. Number of groups of the two types of networks

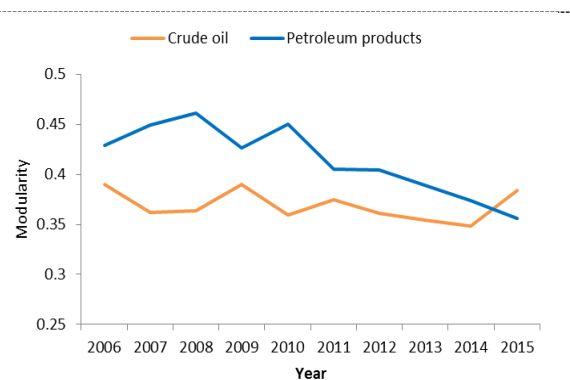


Figure 4. Modularities of the two types of networks

#### 4. Major countries in the communities

The top five countries in trade volume in different communities of crude oil are shown in Table 1. The top five countries in trade volume in different communities of petroleum products are shown in Table 2.

In the network of crude oil, the USA, Russia, Saudi Arabia, China and Japan are the major countries in the communities. These major countries are often in different communities. The geographical factor is becoming more obvious, for example, the USA is tending to in the same community with countries in North and South America; and Russia is tending to in the same community with countries in the Europe.

In the network of petroleum products, the USA, Russia, Saudi Arabia, Singapore, and Netherlands are the major countries in the communities. It should be noted that the position of India in the community is rising. India became the leading countries of its community in 2013 and 2015. The geographical factor is not obvious in the evolution of global pattern of petroleum products.

#### 5. Conclusion

In this paper, the global trade pattern of crude oil and petroleum products are reflected by analysis of communities based on complex network method. The average trade volumes, the network connectivity, the network partition and the major countries in the communities are studied to reveal the evolution of the global pattern. Conclusions are as follows:

(1) The trade volume of crude oil is more than two times of the trade volume of petroleum products and the evolution trends of both volumes are similar. The connectivity of the network of petroleum products is higher than the connectivity of the network of crude oil because the average clustering coefficient of the network of petroleum products is around 0.5, and the average clustering coefficient of the network of crude oil is between 0.2 and 0.3. This result indicates that countries in the world petroleum products market are more related to each other. The partition of the network of petroleum products is greater than that of the network of crude oil because the modularity of the network of petroleum products is more than 0.4 in most of the years, and the modularity of the network of petroleum products is less than 0.4 during the whole period. Countries are clustering into more groups in the network of petroleum products (7 to 9 groups) than that in the network of crude oil (4 to 6 groups). Both networks are becoming less partitioned during the whole period.

(2) The financial crisis in 2008 had obvious impacts on the global trade of both crude oil and petroleum products. An obvious drop of trade volume occurred, and then both of them recovered. However, the impact on the trade pattern has opposite effects. The partition of the network of crude oil was becoming more obvious with an increase of the modularity. The partition of the network of petroleum products was becoming less obvious with a decrease of the modularity.

(3) The major countries in the communities in the network of crude oil are the USA, Russia, Saudi Arabia, China and Japan. The geographical factor is becoming more obvious because countries in the same area are tending to be in the same community. The major countries in the communities in the

network of petroleum products are the USA, Russia, Saudi Arabia, Singapore, and Netherlands. The position of India in the community is rising as it became the leading countries in 2013 and 2015. The geographical factor is not obvious because countries in the same area are often in different communities.

Due to the limit of data, this study only analyzed the evolution of global trade pattern of crude oil and petroleum products between 2006 and 2015. In the future, the study period could be expanded to several decades to reveal more patterns of the two networks.

Table 1. Top five countries in different communities of crude oil

	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
2006	USA	Russia	Saudi Arabia	Nigeria	Fiji	Seychelles
	China	Canada	Japan	Mexico	Wallis and Futuna Isds	Mauritius
	Venezuela	Norway	South Korea	Spain	Gambia	
	Algeria	Germany	UAE	Brazil		
	Angola	UK	Iran	Portugal		
2010	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
	USA	Russia	Saudi Arabia	China	Niger	
	Canada	Germany	Japan	India	Mali	
	Iraq	Netherlands	South Korea	Nigeria		
	Brazil	UK	UAE	Iran		
2013	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
	Saudi Arabia	Russia	Japan	China	Nicaragua	
	USA	Canada	UAE	Angola	El Salvador	
	India	Netherlands	Qatar	Iran		
	South Korea	Nigeria	Thailand	Oman		
2014	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
	Saudi Arabia	Russia	Japan	China	Nigeria	
	USA	Netherlands	UAE	Angola	Spain	
	India	Germany	Qatar	Iran	Brazil	
	Canada	UK	Singapore	Oman	South Africa	
2015	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
	USA	Russia	Saudi Arabia	China	UAE	
	Canada	Nigeria	India	Angola	Japan	
	Venezuela	Netherlands	South Korea	Brazil	Qatar	
	Mexico	Germany	Iraq	Iran	Thailand	
	Colombia	UK	Kuwait	Oman	Singapore	

Table 2. Top five countries in different communities of petroleum products

	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7
2006	USA	Italy	Singapore	Netherlands	Kuwait	Brazil	Trinidad and Tobago
	Russia	Austria	South Korea	Germany	UAE	Algeria	Senegal
	UK	Greece	Japan	France	Pakistan	Argentina	Jamaica
	Canada	Libya	China	Belgium	South Africa	Paraguay	Cote d'Ivoire
	Spain	Slovakia	India	Switzerland	Bahrain	Uruguay	Mali
2010	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7
	USA	Singapore	Netherlands	UAE	Austria	Brazil	Guam
	Russia	South Korea	UK	Kuwait	Slovakia	Algeria	FS Micronesia
	Canada	India	Germany	Saudi Arabia	Hungary	Argentina	Palau
	Italy	China	Belgium	Pakistan	Israel	Paraguay	N. Mariana Isds
2013	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7
	USA	Singapore	Netherlands	India	Hungary	Trinidad and Tobago	FS Micronesia
	Russia	South Korea	Belgium	Brazil	Romania	Jamaica	Guam
	France	Malaysia	UK	Switzerland	Croatia	Suriname	N. Mariana Isds
	Canada	China	Germany	Chile	Georgia	Guyana	
2014	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7
	USA	Singapore	Netherlands	Kuwait	South Korea	Benin	Ecuador



	Canada	Malaysia	Russia	Pakistan	India	Burkina Faso	Panama
	Mexico	Japan	Belgium	Viet Nam	UAE	Cote d'Ivoire	Costa Rica
	Brazil	China	Germany	Bahrain	Spain	Sierra Leone	Zambia
	Colombia	Indonesia	UK	Ethiopia	Italy	Togo	Mauritius
	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7
2015	USA	Singapore	Netherlands	India	Egypt	Trinidad and Tobago	Argentina
	Russia	South Korea	Belgium	Turkey	Austria	Costa Rica	Panama
	Germany	Malaysia	UK	Brazil	Czech Rep.	Bahamas	Paraguay
	France	China	Sweden	Algeria	Slovakia	Jamaica	Bolivia
	Canada	Japan	Norway	South Africa	Romania	Nicaragua	Bunkers

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