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 $E$. $V = \{v_i; i = 1,2, ..., n\}$, $E = \{e_i; i = 1,2, ..., m\}$, $n$ is the number of nodes, and $m$ is the number of edges. The matrix the model is as follows [19]:

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

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:

$$C_i = \frac{n_i}{k_i(k_i-1)}$$ (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. :

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

where $w_{ij}$ is the weight of the edge between node $i$ and node $j$, $A_i = \sum_j w_{ij}$ is the sum of the weights of all the edges of node $i$, $A_j = \sum_i w_{ij}$ is the sum of the weights of all the edges of node $j$, $m = \frac{1}{2} \sum_{i,j} w_{ij}$, $c_i$ 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:

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

(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 $i$, $A_{in}$ 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.
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

| Year | Group 1 | Group 2 | Group 3 | Group 4 | Group 5 | Group 6 |
|------|---------|---------|---------|---------|---------|---------|
| 2006 | USA | Group 2 | Group 3 | Group 4 | Group 5 | Group 6 |
| 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 |
| Algeria | Norway | Kuwait | Angola |
| 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 Africa |
| South Korea | Nigeria | Thailand | Oman |
| Iraq | Germany | Singapore | Portugal |
| 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 |
| South Korea | Norway | Thailand | Portugal | Chile |
| 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

| Year | 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 | 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 |
| Mexico | Japan | France | Qatar | Romania | Gibraltar |
| 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 |
| Mexico | Japan | Sweden | Bahrain | Bosnia Herzegovina | Barbados |
| 2014 | Group 1 | Group 2 | Group 3 | Group 4 | Group 5 | Group 6 | Group 7 |
| USA | Singapore | Netherlands | Kuwait | South Korea | Benin | Ecuador |
References

[1] Garlaschelli, D., et al., *Interplay between topology and dynamics in the World Trade Web*. European Physical Journal B, 2007. **57**(2): p. 159-164.

[2] Halkos, G.E. and K.D. Tsilika, *A Dynamic Interface for Trade Pattern Formation in Multi-regional Multi-sectoral Input-output Modeling*. Computational Economics, 2015. **46**(4): p. 671-681.

[3] Mityakov S, T.H., Tsui KK, *Geopolitics, global patterns of oil trade, and China's oil security quest*. HKIMR Working Paper, 2011. **No.32**.

[4] Zhang, H.Y., Q. Ji, and Y. Fan, *What drives the formation of global oil trade patterns?* Energy Economics, 2015. **49**: p. 639-648.

[5] M, K., *Political limits on the world oil trade: firm-level evidence from US firms*. IDE Discussion Paper, 2013. **No. 401**.

[6] Garlaschelli, D. and M.I. Loffredo, *Structure and evolution of the world trade network*. Physica a-Statistical Mechanics and Its Applications, 2005. **355**(1): p. 138-144.

[7] Fagiolo, G., J. Reyes, and S. Schiavo, *The evolution of the world trade web: a weighted-network analysis*. Journal of Evolutionary Economics, 2010. **20**(4): p. 479-514.

[8] Fagiolo, G., J. Reyes, and S. Schiavo, *World-trade web: Topological properties, dynamics, and evolution*. Physical Review E, 2009. **79**(3).

[9] Duan WQ, L.B., *Research on the measurement and evolution model of world trade networks*. 2011, Beijing: Guangming Daily Press.

[10] Ji, Q., H.Y. Zhang, and Y. Fan, *Identification of global oil trade patterns: An empirical research based on complex network theory*. Energy Conversion and Management, 2014. **85**: p. 856-865.

[11] Guan, Q., et al., *Estimating potential trade links in the international crude oil trade: A link prediction approach*. Energy, 2016. **102**: p. 406-415.

[12] Zhang, H.Y., Q. Ji, and Y. Fan, *Competition, transmission and pattern evolution: A network analysis of global oil trade*. Energy Policy, 2014. **73**: p. 312-322.

[13] An, H.Z., et al., *Features and evolution of international crude oil trade relationships: A trading-based network analysis*. Energy, 2014. **74**: p. 254-259.

[14] Serrano, M.A. and M. Boguna, *Topology of the world trade web*. Physical Review E, 2003. **68**(1).

[15] Barigozzi, M., G. Fagiolo, and G. Mangioni, *Identifying the community structure of the international-trade multi-network*. Physica a-Statistical Mechanics and Its Applications, 2011. **390**(11): p. 2051-2066.

[16] Tzekina, I., K. Danthi, and D.N. Rockmore, *Evolution of community structure in the world trade web*. European Physical Journal B, 2008. **63**(4): p. 541-545.

[17] Zhong, W.Q., et al., *The evolution of communities in the international oil trade network*. Physica a-Statistical Mechanics and Its Applications, 2014. **413**: p. 42-52.

[18] Yang, Y., et al., *Small and flat worlds: A complex network analysis of international trade in crude oil*. Energy, 2015. **93**: p. 534-543.

[19] Zhong, W.G., et al., *Global pattern of the international fossil fuel trade: The evolution of communities*. Energy, 2017. **123**: p. 260-270.

[20] Blondel, V.D., et al., *Fast unfolding of communities in large networks*. Journal of Statistical Mechanics-Theory and Experiment, 2008.