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Small and flat worlds: A complex network analysis of international trade in crude oil

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ABSTRACT

Global competition for crude oil has increased in the past decade with the entry of industrializing nations such as China and India. Yet we still do not know much about the spatial structure of crude oil commodity trade and its evolution over time. In this paper, we apply complex network analysis to examine the geography of global crude oil flows and its evolution based on the United Nations commodity trade database from 1988 to 2013. Attention is given to the geo-visualization of the networks that trace the rise and decline of oil hubs. The results show that world crude oil is characterized by network characteristics that capture both small world and flat world properties.

1. Introduction

The year 2015 began with a precipitous fall in oil prices to below \$50 per barrel. Yet oil production has continued unabated by major exporting countries in the Middle East and the United States (US). Fueled by demand as industrial production expanded both in developed countries and developing countries in Asia and Latin America, the value of international trade in oil rose from US\$37 billion in 1988 to US\$1626 billion in 2013. This represents a forty-fold increase in 25 years. Oil is not only a main source of fuel that drives most modern economic activities, but it is also the basis of manufactures such as plastics and fertilizers in the petrochemical industry. As a strategic natural resource, crude oil accounts for 33.5% of world energy consumption with more than 60% of global oil consumption being met by imports in the past ten years [1]. Despite its importance in global economic outlook, not much work has been done on crude oil trade with few exceptions (see below). This paper seeks to augment this body of work by examining the spatial dynamics of the international trade of crude oil through the integration of GIS (geographical information system) and complex networks. Network analysis has gained popularity because of its ability to represent the world trading system through the organization of spatial attributes [2]. It is useful for capturing the level of connectivity between countries [3]. Applying complex network model allows us to examine the changing structure of oil trade over time. A scale-free network perspective draws attention to the interconnections between countries [4,5]. Integrating GIS with networks facilitates the geo-visualization of international oil trade in graphical representations.

In general, empirical studies of the spatial dynamics of trade have shown that the international trading system has become more interconnected over the past three decades [6,7]. Nonetheless, they also found that the system tends to be composed of small-worlds — the idea that people, firms and countries are highly connected. The small world phenomenon may be traced to social psychologist Stanley Milgram as well as Watts and Strogatz who showed that the number of connections or edges between two nodes is fairly short on average [8,9]. Specifically, they found that the average number of intermediaries from a sender (originating country) to target receiver (destination country) is about six leading to the general rule that two nodes are characterized by six degrees of separation. In other words, the small world phenomenon describes a locally clustered network structure with a short path length between two otherwise divergent network characteristics. The relevance of the small world phenomenon is that it can potentially shed light on trade behavior by shaping the level of connectivity among

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countries embedded in the world trading system. The more a network displays small world characteristics, the higher the level of connection between countries implying a deepening collaboration with one another or through a third common country [10]. This facilitates trade circulation in clusters that are otherwise separate increasing the likelihood that resources from one cluster may be accessible or shared by another cluster. In the context of trade, clustering also leads to the regionalization of supply chains to capture the advantages of regional economies of scale and lower transaction costs among firms [11,12].

At the same time, international production is increasingly spatially fragmented across GVCs (global value chains) as firm exploit locational differences in factor endowments and regulatory environments. Suppliers and subcontractors in developing countries are joining the world trading system by participating in GVCs [13]. The export volume of developing countries for instance doubled between 2000 and 2008 compared to a 50% increase of world exports over the same period (www.WTO.org). Participation of a greater number of countries in international trade is accompanied by geographical diversification of trade relationships, a flatter world as Thomas Friedman has suggested [14]. In contrast to small world that stresses the spatial proximity of trade connections, flatter worlds are consistent with a more globalized world economy, a larger world that is driven by trade connections over longer distances or spatially dispersed locations [15,16]. The flat world thesis was first proposed by O'Brien over twenty years ago [17]. He concluded that distance has become an irrelevant barrier for investment and trade in the age of globalization. A country can trade with partners that are located farther away as transportation costs have fallen. The world topography has effectively become flatter because firms are highly mobile in space and can relocate their facilities to distant countries to exploit lower costs, source for inputs, or explore new markets. The relocation of factories, warehouses or logistical centers to far-flung countries in turn generates more connections between countries that result in a flatter world. The crude oil trade is especially global in geographical scope because it is not a ubiquitous resources. It is geographically concentrated in a few countries although technology has uncovered new sources in non-traditional areas [18]. Demand for oil however is spatially dispersed generating more connections in long distance trade for example between the Middle East and East Asia.

Under a complex network approach, oil trade spatial structure is examined in terms of the degree and strength of connectivity between countries; hence the focus is on how oil flows are distributed across the network. Some studies found evidence of small world properties [12,19]. Others have shown the opposite, that is, trade is more spatially diffused [20]. In the oil trade, there appears to be support for increased global connectivity [21]. This paper contributes to the literature by integrating both small and flat world approaches through complex network analysis and GIS geovisualization. Some countries, for example those in NAFTA and EU, establish trade clusters with nearby countries because they share a common culture and history. Firms are likely to be more familiar with the needs of neighboring markets and trade more intensively across common borders [11,22]. Others including resource-poor East Asia or small countries may establish trade connections across the globe to source for raw materials like oil. This paper will show that the oil trade landscape is not reduced to one spatial outcome, that is, small *or* flat world. Rather we hypothesize that both outcomes may be found simultaneously.

In the next section, major network measures are outlined and described. These include indices of network connectivity, centrality and community structure. This is followed by a discussion of the results of network analysis. The paper concludes with a summary of the major findings.

2. Network measures and data

2.1. Network construction

Under the complex network model, trade relationships between countries may be graphically captured by a collection of vertices (nodes) and edges or links. Networks can be directed or non-directed. In non-directed networks, exporting and importing nodes are indistinguishable in a dyad, and edge direction is of little interest. In the case of a directed network, country A exports to country B, but country B may not export to country A. Likewise, country X imports from country Y, but country Y may not import from country X. The data indicates that crude oil flows are better captured in directed networks or a diagraph since oil production is highly concentrated spatially. Global crude oil directed network may be represented by a set $G = (V,E)$, such that country nodes $V = \{v_1, v_2, \cdots, v_n\}$ represent network nodes, and trade relationships set $E = \{e_{ij}\}$ denote network edges. n is the number of countries, while i and j are sending and receiving countries respectively (i and j range from 1 to n respectively). As the analysis will map 1990, 2000 and 2013, n is smallest in 1990 with just 69 countries that are involved in world oil trade. But it increased to 150 countries by 2000, and remained stable at that size in 2013. The adjacency matrix $e_{ij} = 1$ if node v_i exports to node v_j, otherwise $e_{ij} = 0$. If an edge is established between two nodes, then they are trade partners or geographical neighbors. Since trade volumes vary greatly, such differences should be taken into account. In this paper, we construct crude oil trade flows as the weight of edges. w_{ij} represents export from country v_i to country v_j. If there is no export from v_i to v_j, then $w_{ij} = 0$. The weighted directed crude oil network matrix may be given as follows:

$$W = \begin{bmatrix} w_{11} & \cdots & w_{1m} \\ \vdots & \ddots & \vdots \\ w_{n1} & \cdots & w_{nm} \end{bmatrix}$$

2.2. Network measures

2.2.1. Connectivity

The overall network connectivity may be calculated from two measures. The first is associated with network density indices, and the second with network diameter and length. Network density indices α, β, γ may be expressed as:

$$\alpha = \frac{2(e - v + 1)}{(v - 1)(v - 2)} \tag{1}$$

$$\beta = \frac{e}{v} \tag{2}$$

$$\gamma = \frac{2e}{v(v - 1)} \tag{3}$$

In (1), (2) and (3), e denotes the edges of the directed network, and v refers to network nodes. α is the ratio of actual to maximal number of circuits in a fully connected network, β is the average number of edges per node, and γ is the ratio of actual to maximal number of edges [23]. α and γ lie between the values of 0 and 1 with 1 being fully connected. In the case of β the higher its value, the better connected is the network.

The second connectivity measure is associated with the network's diameter D and average path L. Denoting the topological