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Driving force and resistance: Network feature in oil trade

Toshihiko Kitamura[a], Shunsuke Managi[b,*]

[a] Department of Urban and Environmental Engineering, School of Engineering, Kyushu University, Motooka 744, Nishi-ku, Fukuoka 819-0395, Japan
[b] Urban Institute & Department of Urban and Environmental Engineering, School of Engineering, Kyushu University, Motooka 744, Nishi-ku, Fukuoka 819-0395, Japan

HIGHLIGHTS

- Driving force and resistance in bilateral trade are analyzed using the gravity equation.
- Networks of crude oil trade and petroleum trade are constructed.
- Competitive or cooperative relationships among countries are revealed.

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ABSTRACT

This article examines the international crude oil trade and the international petroleum trade through econometric analysis and complex network analysis, focusing on the aspects of the driving forces and resistances for the oil trade and competitive or cooperative relationships among countries. The crude oil trade network and the petroleum trade network are constructed. Positional and role analysis reveals that countries can be divided into five positions in the crude oil trade network and twenty-five positions in the petroleum trade network. The relationships among countries within or between positions are discussed and recognized as competitive or cooperative. The bilateral oil trade analysis shows that various factors within countries have influence on bilateral trade volume. The analysis also implies that restrictions on trade partner selection due to geographical resistance forces neighboring oil-importing countries to choose similar oil-exporting countries, which corresponds with the results of the complex network analysis. The complex network analysis shows that the countries in the same position belong to the same region. Furthermore, the analysis results imply that the diversification in petroleum-exporting countries reduces the supply disruption risk for importing countries.

1. Introduction

The international oil trade attracts the world's attention due to oil's large share of energy consumption and because oil-exporting countries have a high degree of political instability. In addition, global oil consumption has been steadily increasing. The countries outside the Organization for Economic Co-operation and Development (OECD) account for most of the net growth in global oil consumption [1]. China and India have provided the largest contributions to the growth of oil consumption [2]. There is an imbalance in the distribution of oil resources and oil consuming areas in the world, and international oil trade plays an important role in connecting oil producers with oil consumers. Oil acquisition competition, due to the steady increase in oil consumption, is expected in the international oil trade. Thus, energy security and competition, due to emerging economies in the international oil trade, are the main concerns of oil-importing countries. Therefore, features of the global oil trade are becoming increasingly important to understand.

This paper aims to analyze the national attributes influencing bilateral oil trade volume and the relationships between countries in the international oil trade. We evaluate the international oil trade using the gravity equation from the following viewpoint, in addition to the commonly evaluated factors in the studies of international trade: whether oil trade volume is inversely proportional to bilateral distance, as oil reserves are unequally located in the world. In addition, we make use of the positional and role analysis to simplify the international oil trade to make it easier to understand and to acquire information about competition and cooperation related to trade and energy security. These dynamics are determined by the relationships among constituent countries in an oil trade network rather than a bilateral oil trade relationship. We also examine international petroleum (excluding crude) trade.

The main contributions of this study are as follows: (1) we analyze the driving forces and resistances in bilateral oil trading using the gravity equation, some of which have not been investigated in previous

* Corresponding author.
E-mail addresses: t-kitamura@doc.kyushu-u.ac.jp (T. Kitamura), managi@doc.kyushu-u.ac.jp (S. Managi).

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international trade studies: (2) the crude oil trade and petroleum trade networks are constructed and provide information on possible competitive or cooperative relationships among countries, which may be beneficial for policy makers to consider for an oil procurement policy: (3) we analyze the international petroleum trade, which is rarely analyzed in oil trade studies.

This paper is structured as follows. Section 2 provides a methodology review for the international trade study. Section 3 explains the econometric analysis and complex network analysis and provides a description of the data. Section 4 presents the evaluation results. Section 5 provides a discussion, while Section 6 presents the conclusions.

2. Methodology review

Since Tinbergen [3] introduced the gravity equation, it has frequently been applied to the investigation of international trade. The gravity equation describes trade flows and states that bilateral trade is proportional to both countries' gross domestic products (GDPs) and inversely proportional to their distance (see Silva and Tenreyro [4] for review). The distance is a resistance for facilitating bilateral trade, which reflects transport costs. The gravity equation is applied to estimating effects of various factors (see Kagohashi et al. [5], Managi et al. [6], and Tsurumi and Managi [7] for its applications). In addition to countries' GDPs and their distances, other commonly examined factors in international trade studies include national borders [8] and preferential trade agreements (PTAs) [9]. Some studies applied the gravity equation to the international energy resource trade [10].

An et al. [11] noted that traditional trade theories have some limits in analyzing the international crude oil trade as a system with numerous countries and complicated relationships. Network analysis has strength in understanding the overall features of international trade. Snyder and Kick [12] proposed the blockmodel of the world system based on international networks. Since then, a variety of blockmodeling has been conducted for international trade studies [13–16]. Much literature has also studied topological properties of international trade and their evolution over time [17–19].

Recently, studies of the international energy resource trade have used the complex network analysis [20–28]. Researchers have measured indexes of an oil trade network such as degree, cluster coefficient, density and centrality. Some studies have found that the number of trade relationships follows the power law distribution and the oil trade network displays a scale-free behavior [29,30]. Many studies detected communities in the oil trade [29,31]. Ji et al. [30] also found such communities and showed that the global oil trade network could be divided into three blocks: the South America-West Africa-North America trading block, the Middle East-Asia Pacific region, and the former Soviet Union-North Africa-Europe trading block. The study succeeded in showing the current oil trade's regional structure. However, we intend to evaluate the country-level relationships in these regions, as our purpose is to investigate competition in the oil trade. Zhang et al. [32] presented the oil trade's competitive relationships among regions and the bilateral direct relationships with the largest competition intensity. However, policymakers may wish to know about the relationships among countries within a region to discuss specific policies on oil procurement.

The positional and role analysis in social networks identifies social positions as collections of actors who are similar in their ties with others, modeling social roles as systems of ties between actors or between positions [33]. White et al. [34] introduced blockmodels of social structure, which identified the role and position concepts. The analysis uses the relationship of so-called structural equivalence. The Euclidean distance and correlation coefficient are commonly used to measure structural equivalence. Ji and Fan [35] examined the crude oil market with the 24 oil trading countries' data, calculating correlation coefficients of countries' oil price returns to examine correlation and compactness between markets (see Geng et al. [22] for an example of a natural gas market). The actors in the same position may be in a competitive or cooperative relationship.

In this study, we use both the traditional trade theory, using the gravity equation, and the complex network analysis to compensate for the limits of the analysis traditionally used to investigate the international oil trade. In the traditional analysis, we examine known key factors in oil trading countries in addition to the commonly evaluated factors in international trade studies. In the complex network analysis, we use the positional and role analysis to examine competitive or cooperative relationships among countries in the international oil trade.

3. Method

3.1. Effects of national attributes on oil trade

We apply a common empirical method to the international oil trade, and the following is the typical gravity equation used (see Tsurumi et al. [36] for review):

$$T_{ij} = \alpha_0 \frac{Y_i Y_j}{D_{ij}}, \tag{1}$$

where T_{ij} is the trade flow from country i to country j, Y_i and Y_j are country i's GDP and country j's GDP, respectively, D_{ij} is their distance, and α_0 is the constant. The log linear formation of the gravity equation is expressed as follows:

$$\log T_{ij} = \log\alpha_0 + \alpha_1 \log Y_i + \alpha_2 \log Y_j + \alpha_3 \log D_{ij} + \varepsilon_{ij} \tag{2}$$

This model has been estimated by ordinary least squares (OLS) in many empirical studies. However, Silva and Tenreyro [4] found that the error term in the log linear form of the gravity equation was heteroskedastic, which violated the condition for consistency of OLS. They also noted that trade values of zero were observed and there were problems with the log linear form of the gravity equation. They recommended that the Poisson pseudo maximum likelihood (PPML) estimator be used to estimate the gravity equation.

$$T_{ij} = \exp(\log\alpha_0 + \alpha_1 \log Y_i + \alpha_2 \log Y_j + \alpha_3 \log D_{ij}) + \varepsilon_{ij} \tag{3}$$

We use the following empirical equation:

$$\begin{aligned} T_{ij} = \exp(&\log\alpha_0 + \alpha_1 \log Y_i + \alpha_2 \log Y_j + \alpha_3 \log D_{ij} + \alpha_4 \log GPI_i + \alpha_5 \log GPI_j \\ &+ \alpha_6 \log Reserve_i + \alpha_7 \log Reserve_j + \alpha_8 dAdj + \alpha_9 dOPEC + \alpha_{10} dPTA \\ &+ \alpha_{11} dCol + \alpha_{12} dLanguage) + \varepsilon_{ij}, \end{aligned} \tag{4}$$

where T_{ij} is the trade flow from country i to country j; Y_i and Y_j are country i's GDP and country j's GDP, respectively; D_{ij} is their distance[1]; $Reserve_i$ and $Reserve_j$ are the proven oil reserves of country i and country j; GPI_i and GPI_j are the Global Peace Indexes (GPIs)[2] of country i and country j; $dAdj$ is the contiguity dummy, assuming the value 1 if both countries share a land border and 0 otherwise; $dOPEC$ is the Organization of Petroleum Exporting Countries (OPEC) dummy, assuming the value 1 if an exporting country is a member of OPEC and 0 otherwise; $dPTA$ is the preferential trade agreement dummy,[3] assuming the value 1 if both countries are members of a preferential trade agreement and 0 otherwise; $dCol$ is the colonial-tie dummy, assuming the value 1 if both countries have a colonial tie and 0 otherwise; $dLanguage$ is the language dummy, assuming the value 1 if both countries speak the same language and 0 otherwise; $\alpha_0,\alpha_1,\alpha_2,\alpha_3 ..., \alpha_{12}$ are the unknown parameters; and ε_{ij} is the error. The lists of countries and regions, OPEC member countries, preferential trade agreements, colonial ties and countries

[1] The great circle distance (angular difference) between two points is used.

[2] The GPI measures a country's level of Negative Peace based on research in three domains; ongoing domestic and international conflicts, societal safety and security, and a country's militarization [37].

[3] The coefficient for the PTA dummy variable indicates an average treatment effect of the preferential trade agreements listed in Table A.3 in Appendix A.