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The network analysis of oil trade under deep uncertainty

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Abstract

Oil is essential in many spheres of industries and play key role in economies of different countries. A reduction in oil supplies or production may affect the situation in a country. We have constructed a network of export/import of oil and analyzed scenarios when a reduction in the oil supply takes place. The countries most dependent on imports of oil have been identified.

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Keywords: network analysis; deep uncertainty; scenario analysis; oil trade

1. Network analysis of oil trade

To construct the process of oil trade we use network analysis. The countries are represented as the vertices, and the edges with weights represent the cost of export/import amounts of products sent from country i to country j.

One of the main aims for networks analysis is to identify key vertices. There are serval classic centrality indices such as Eigenvector centrality, PageRank centrality, etc. In [1] it is argued that most of publications on classical centrality indices do not take into account parameters and group influence of vertices.

In [2] new classes of centrality indices in networks are introduced which take into account properties of vertices and group influence. It is considered a directed weighted graph $G^0(V,W^0)$, V – set of vertices, $|V| = n$, W^0 – set of edges $\{i,j\}$, $\{i,j\} \in V$ with weights w_{ji}^0.

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For each $i \in V$ it is defined the quota q_i and the maximum number k of vertices which can simultaneously influence a node.

In [3] there are considered the following centrality indices.

- In-degree index CI^0
  For each $i \in V$ it is defined

$$CI^0(i) = \sum_j w_{ji}^0 \tag{1}$$

In other words, $CI^0(i)$ is equal to sum of weights of incoming edges.

- Group influence index BI^0
  For each $i \in V$ it is defined the set S, $S \subseteq V \setminus \{i\}, |S| \le k, \forall j \in S, w_{ji}^0 \ne 0$. The bundle index for $i \in V$ is defined

$$BI^0(i) = \sum_S BI_i^0(S), \tag{2}$$

where $BI^0(i)$ is equal to 1 if $\sum_{j \in S} w_{ji}^0 \ge q_i$, and 0 otherwise.

In other words, $BI^0(i)$ is equal to the number of sets (we call them critical sets), which has not more than k incoming edges and the sum of weights not less than q_i.

- Pivotal index

  The node $j_p \in V$ is called pivotal for the node $i \in V$, if

$$\sum_{j \in S} w_{ji}^0 \ge q_i, \sum_{j \in S \setminus \{j_p\}} w_{ji}^0 < q_i \tag{3}$$

The pivotal index for $i \in V$ is defined

$$PI^0(i) = \sum_S PI(S) \cdot |S|, \tag{4}$$

where $PI_i^0(S)$ is the number of pivotal nodes $j_p \in S$. In other words, $PI^0(i)$ is the number of pivotal nodes in all critical sets S.

- Total index TI^0

  For each $i \in V$ it is defined as

$$Ti^0(i) = \alpha_1 CI^0(i) + \alpha_2 BI^0(i) + \alpha_3 PI^0(i), \tag{5}$$

where $\alpha_1 + \alpha_2 + \alpha_3 = 1, \alpha_1, \alpha_2, \alpha_3 \ge 0$. In other words, the total index for $i \in V$ is equal to the weighted arithmetic mean of In-degree, Group influence, Pivotal indices.

In [3] an indirect influence is introduced. Parameter $d > 0$ is the acceptable length of path between nodes. For directed weighted graph $G^0(V, W^0)$ it is constructed graph $G^d(V, W^d)$ in the following way:

$$P_{jk_{11} \ldots k_{1d-1}i} = \min(w_{jk_{11}}^0, \ldots, w_{k_{1d-1}i}^0), \tag{6}$$

$$P_{jk_{21}...k_{2d-1}i} = \min(w^0_{jk_{21}},...,w^0_{k_{2d-1}i}), \tag{7}$$

…

$$P_{jk_{t1}...k_{td-1}i} = \min(w^0_{jk_{t1}},...,w^0_{k_{td-1}i}), \tag{8}$$

$$w^d(ji) = \max(P_{jk_{11}...k_{1d-1}i}, P_{jk_{21}...k_{2d-1}i},...,P_{jk_{t1}...k_{td-1}i}) \tag{9}$$

For the graph $G^d(V,W^d)$ the centrality indices BI^d, CI^d, PI^d, TI^d are defined which are calculated in the same way as BI^0, CI^0, PI^0, TI^0 for the graph $G^0(V,W^0)$.

For example, consider three countries (A,B,C) in the trade network of the product. Country A exports to country C rare-earth metal compounds by \$100 $(w^0_{BC} = 100)$, country B exports to C by \$50 $(w^0_{BC} = 50)$, C exports to D by \$200 $(w^0_{BC} = 200)$. This can be represented as directed weighted graph with weights on its vertices and edges (see Fig. 1).

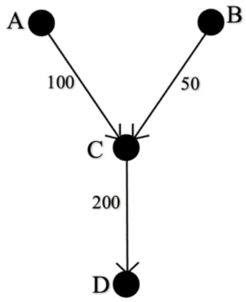

Fig. 1. An example of network

For the considered example, $CI^0(A) = 0, CI^0(B) = 0, CI^0(C) = 50 + 100 = 150, CI^0(D) = 200.$ Assume that $q_A = q_B = q_C = q_D = 60, k = 2.$ Then, we have

$$BI^0(A) = \sum_S BI^0_A(S) = 0, \tag{10}$$

$$BI^0(B) = \sum_S BI^0_B(S) = 0, \tag{11}$$

$$BI^0(C) = \sum_S BI^0_C(S) = BI^0_C(\{A,B\}) + BI^0_C(\{A\}) + BI^0_C(\{B\}) = 2, \tag{12}$$

$$BI^0(D) = \sum_S BI^0_D(S) = BI^0_D(\{C\}) = 1, \tag{13}$$

$$PI^0(A) = \sum_S PI^0_A(S) \cdot |S| = 0, \tag{14}$$

$$PI^0(B) = \sum_S PI^0_B(S) \cdot |S| = 0, \tag{15}$$

$$PI^0(C) = PI^0_C(\{A,B\}) \cdot 2 + PI^0_C(\{A\}) \cdot 1 + PI^0_C(\{B\}) \cdot 1 = 2 + 1 + 0 = 3, \tag{16}$$

$$PI^0(D) = \sum_S PI_D^0(S) \cdot |S| = PI_D^0(\{C\}) \cdot 1 = 1 \quad (17)$$

Suppose that $\alpha_1 = \alpha_2 = 0.3, \alpha_3 = 0.4.$ Then,

$$TI^0(A) = 0, \quad (18)$$

$$TI^0(B) = 0, \quad (19)$$

$$TI^0(C) = 0.3 \cdot 150 + 0.3 \cdot 2 + 0.4 \cdot 3 = 45 + 0.6 + 1.2 = 46.7 \quad (20)$$

$$TI^0(D) = 0.3 \cdot 200 + 0.3 \cdot 1 + 0.4 \cdot 1 = 60 + 0.3 + 0.4 = 60.7 \quad (21)$$

For this graph, $P_{ACD} = \min(w_{AC}^1, w_{CD}^1) = \min(100, 200) = 100$, $P_{BCD} = \min(w_{BC}^1, w_{CD}^1) = \min(50, 200) = 50$, $w^1(AD) = 100, w^1(BD) = 50.$

It is clearly, that for $d = 1$ agents A, B have an influence on C.

2. Data Sources

The following main sources are used in this paper:

- The UN Comtrade database [4], which provides annual statistics on bilateral trade in goods broken down by category, from 1962 to 2021. The HS (Harmonized System) commodity classification system with code 2709 for crude oil is used.
- Data from the U.S. Energy Information Administration (EIA) were used to clarify the structure of U.S. imports and exports [5].
- The import structure of the European Union countries was reconstructed according to Eurostat [6]
- Data on total imports, exports, production, consumption of individual countries were provided by the International Energy Agency (IEA) [7], information resources of the Organisation of Petroleum Exporting Countries (OPEC) [8], Statistical Review of World Energy prepared by BP Corporation [9].
- Real GDP, real GDP per capita from the World Bank were used for estimation of the level of economic development of countries.

The HS (Harmonized System) commodity classification system with code 2709 for crude oil is used. Petroleum products are not considered in the study, so there are no non-processing countries among the importers. The analysis is presented for the period from 2000 to 2021. It is assumed that for the same flow the importer and exporter publish the same delivery value. However, more often the values of the flows do not coincide, sometimes significantly. Therefore, initial preprocessing of the data was carried out.

3. Data pre-processing

The trade relations of countries are represented as two time series: each series corresponds to the publications of one country. The objective is to obtain a single value for each flow.

3.1. Removing outliers with low reliability

In the first step, each pair of time series is compared with each other in order to identify obvious errors in the publications.

If there is a significant difference between the flows published by different countries, the less reliable publication is excluded from consideration unless other sources are available to supplement the information. The criterion for reliability is a higher degree of consistency with neighbouring values and with data on total imports/exports. Azerbaijan reports shipments of 718,000 bpd in 2008, more than three times as much as in neighbouring years. Italy does not register a significant increase in shipments. For 2008 Azerbaijan's exports are systematically overestimated (Azerbaijan's total exports in 2008 according to UN Comtrade are 3.5 times higher than actual total exports according to the OPEC). In such a situation, the statistics of the country whose data are more consistent with the trend (in this case Italy) is chosen.

3.2. Filling omissions

The second step solves the problem of omissions, where neither country reports trade. For example, Saudi Arabia is the largest oil supplier to Japan. However, according to UN Comtrade, there was no trade flow between the countries in 2017. Although supplies were increased by more than 100,000 bpd compared with 2016 [10, 11]. Such data gaps are filled by the average of neighbouring years if no sources were available to reconstruct the exact volume of supply.

The third stage deals with special cases.

3.3. Special cases

3.3.1. Significant differences in the values of export flows to European countries

According to the recommendations of the United Nations Statistical Commission, as a supplier, the importer should list the country of origin and the exporter should list the country of final consumption [12]. However, often exporters publish data on exports to an intermediate country. This is one of the main reasons for the inconsistency of published data. Europe has an extensive oil transportation system, so the published supply volumes of exporters often do not coincide with the volumes published by importers. Suppliers publish statistics on shipments to countries from which oil is transported onward through pipelines. The most important pipelines are:

- RAPL (Rotterdam-Antwerp Pipeline) with a capacity of 575,000 bpd, connecting Rotterdam (Netherlands) and Antwerp (Belgium) [13]
- The RRP (Rotterdam-Ruhr Pipeline) with a capacity of 320,000 bpd connects Rotterdam with refineries in West Germany (Wesel, Gelsenkirchen) [13].
- TAL (Transalpine Pipeline), with a capacity of 850,000 bpd, crosses Italy, Austria, Germany and connects the port of Trieste with Bavaria, Barden-Württemberg. Additional pipeline branches supply crude oil to the Czech Republic and Austria. The pipeline supplies 100% of Southern Germany's demand, 90% of Austria's demand and 50% of the Czech Republic's demand [14].

For this reason, exporters report larger shipments to the Netherlands, Italy and smaller ones to Germany, Belgium and France.

Eurostat data are used to reconstruct the import structure of EU countries [8].

3.3.2. Saudi Arabia's crude oil exports to the Kingdom of Bahrain

The Sitra refinery imports more than 85% of its crude oil from Saudi Arabia. More than 220,000 barrels per day are supplied by the Saudi Aramco Corporation [15]. However, until 2012, Bahrain did not peport detail imports by country (reporting only total imports); after 2012, Saudi Arabia is the only supplier. Saudi Arabia's exports to the Kingdom of Bahrain are recovered using OPEC data on Bahrain's total imports [8]. All crude oil supplies are assigned to Saudi Arabia.

3.3.3. Unsatisfactory data on Turkey's imports

Data on Turkish imports are only available up to 2006. The structure of imports has been reconstructed from Eurostat data [6].

3.3.4. Inconsistencies in the publications of Malaysia and China

Since 2015, Malaysia's export statistics to China, previously almost identical, have diverged significantly. According to Malaysia's trade statistics, exports to China have not increased, but China has recorded explosive growth. In 2015 the USA imposed sanctions against Venezuela and, in 2017, additional sanctions against oil industry. In 2018 the US imposed sanctions on Iran, urging crude importers to reduce purchases. According to [16, 17] Iranian and Venezuelan oil enters the Straits of Malacca and is transferred to large Chinese tankers. In the paper, Malaysia's surplus exports (imports according to Chinese statistics minus exports according to Malaysian statistics) were divided between Venezuela's and Iran's surplus exports to Southeast Asian countries. Excess exports are the difference between Iran's and Venezuela's exports to Southeast Asia according to OPEC [8] and the imports recorded by importers in the region. For example, in 2020, Venezuela's and Iran's surplus exports to Southeast Asia were 250,000 and 300,000 bpd respectively. Malaysia's surplus exports to China were 230,000 bpd. Therefore, Venezuela's and Iran's exports to China were increased by an additional 103.5 (45%) and 126.5 (55%) thousand bpd respectively.

3.3.5. India's lack of import structure between 2000 and 2006

Between 2000 and 2006, the data contain only India's total imports without specifying the exporting countries. Flows from 2001 to 2006 were reconstructed from Reuters data [18]. The structure of imports for 2000 was filled in with the average values for 1999 and 2001.

3.4. Obtaining a single value for the series

The final preprocessing step is to obtain a single value for the flows recorded by both parties. To solve this problem, the flow re-weighting procedure proposed in [19] is applied.

4. Scenario analysis

The situation of deep uncertainty is defined by the absence of any statistical evaluations of the situation development [20]. We use scenario analysis to model the consequences of events affecting exports/imports in the network under deep uncertainty and consider the model of oil trade network to identify critical countries in case of export/import quantities change. For example, we assume that the use of renewable energy sources is growing. European countries reduced its import of oil.

Quota q_i for country i is calculated according to the following principle. First, the average oil imports over the last 5 years are calculated (M). Then the coefficient of change of real GDP compared to the previous year is calculated (K). If the coefficient is less than 1 (falling GDP), the quota is equal to the product of M and K. If real GDP has risen ($K > 1$), the quota remains equal to M. The quota is calculated for each importer for each year. Data on real GDP are taken from the World Bank [21]. Pre-processed data were used to estimate the volume of oil imports.

5. Results

The list of TOP-5 countries by considered centrality indices in 2021 are presented in Table 1.

Table 1. TOP-5 countries in 2020

In-degree CI^0	Group influence BI^0	Pivotal PI^0
China	Brunei Darussalam	Brunei Darussalam
USA	Vietnam	Panama
India	Panama	Vietnam
Republic of Korea	Uzbekistan	Hungary
Japan	Ukraine	Brazil

Assume now that some European countries (Greece, Slovakia, Croatia, Albania, Netherlands, Spain, Hungary, Norway, Germany, France, Sweden, Romania, Austria, Finland, Denmark, Belarus, Bosnia Herzegovina, Belgium, Montenegro, Italy, Switzerland, Latvia, Lithuania) reduced its import of oil by 5% and 10% for the scenario 1 and scenario 2 respectively. The list of TOP-5 countries by considered centrality indices for scenarios 1, 2 are presented in Tables 2 and 3 respectively.

Table 2. TOP-5 countries for the scenario 1.

In-degree CI^0	Group influence BI^0	Pivotal PI^0
China	Brunei Darussalam	Brunei Darussalam
USA	Vietnam	Panama
India	Panama	Vietnam
Republic of Korea	Uzbekistan	Hungary
Japan	Ukraine	Brazil

Table 3. TOP-5 countries for the scenario 2.

In-degree CI^0	Group influence BI^0	Pivotal PI^0
China	Brunei Darussalam	Brunei Darussalam
USA	Vietnam	Panama
India	Panama	Vietnam
Republic of Korea	Uzbekistan	Brazil
Japan	Ukraine	Uzbekistan

Let’s note that when the scenario 2 is considered Hungary is not vulnerable country to the supply of oil in turns of Pivotal index. But in general, the same countries are strongly depended on the oil supply.

6. Conclusion

We have constructed the model of oil trade under deep uncertainty. Scenario analysis of consequences for countries has been performed for each network based on real data of export and production. Most vulnerable countries have been found by classic and new centrality indices.

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References

[1] Newman, M. E. (2003). The structure and function of complex networks. *SIAM review*, *45*(2), 167-256.

[2] Aleskerov, F., Shvydun, S., & Meshcheryakova, N. (2021). New Centrality Measures in Networks: How to Take Into Account the Parameters of the Nodes and Group Influence of Nodes to Nodes. Chapman and Hall/CRC.

[3] Aleskerov F., & Yakuba V. (2020) Matrix-vector approach to construct generalized centrality indices in networks / NRU Higher School of Economics. Series WP7 "Mathematical methods for decision making economics, business and politics".

[4] UN Comtrade Database. Retrieved from https://comtradeplus.un.org/

[5] U. S. Energy Information Administration. Retrieved from https://www.eia.gov/

[6] Eurostat Data Browser. Imports of oil and petroleum products by partner country. Retrieved from https://ec.europa.eu/eurostat/data/database

[7] International Energy Agency. Countries and regions. Retrieved from https://www.iea.org/countries

[8] OPEC. Annual Statistical Bulletin 2022. Retrieved from https://asb.opec.org/

[9] BP. Statistical Review of World Energy 2022 | 71st edition. Retrieved from https://www.bp.com/en/global/corporate/news-and-insights/reports-and-publications.html

[10] Reuters. Market Eye: Saudi Crude Supplies to Japan Surge in 2017. Retrieved from https://www.energyintel.com/0000017b-a7d3-de4c-a17b-e7d3f4810000?view=secondary-register

[11] Reuters. Saudi Arabia crude-oil exports. Retrieved from https://fingfx.thomsonreuters.com/gfx/editorcharts/SAUDI-ARAMCO-EXPORTS/0H001QX6Q8E6/index.html

[12] UN Statistics Wiki. Bilateral asymmetries. Retrieved from https://unstats.un.org/wiki/display/comtrade/Bilateral+asymmetries

[13] European Chemical Site Promotion Platform. An Overview of the Pipeline Networks of Europe. Retrieved from https://chemicalparks.eu/europe/pipeline-networks

[14] TAL|Transalpine Pipeline. Company Profile. Retrieved from https://www.tal-oil.com/en/tal-group/company-profile

[15] Reuters. Bahrain's Bapco sees oil trading opportunities as it expands refinery. Retrieved from: https://www.reuters.com/article/bahrain-oil-refinery-idUKL5N20U4SA

[16] Nikkei Asia. Iranian oil flowing past Malaysia on way to Asian customers. Retrieved from https://asia.nikkei.com/Politics/International-relations/Iranian-oil-flowing-past-Malaysia-on-way-to-Asian-customers

[17] Reuters. Analysis: Venezuelan oil, masked as Malaysian, rushes into China before fuel tax. Retrieved from https://www.reuters.com/business/energy/venezuelan-oil-masked-malaysian-rushes-into-china-before-fuel-tax-2021-06-04/

[18] Reuters. Table-India's country-wise crude oil imports since 2001/02. Retrieved from https://www.reuters.com/article/india-crude-import-idINL4E8IU4HI20120806

[19] Meshcheryakova, N. (2020, December). Network analysis of bilateral trade data under asymmetry. In 2020 IEEE/ACM International Conference on Advances in Social Networks Analysis and Mining (ASONAM) (pp. 379-383). IEEE.

[20] Bloemen, P. J., Hammer, F., van der Vlist, M. J., Grinwis, P., & van Alphen, J. (2019). DMDU into practice: Adaptive Delta Management in the Netherlands. Decision making under deep uncertainty: From theory to practice, 321-351.

[21] Energy Intelligence. Taiwanese Crude Oil Imports by Country of Origin. 2005-2010. Retrieved from https://www.energyintel.com/0000017b-a7c4-de4c-a17b-e7c678820000