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Exposure to trade disruptions in case of the Russia-Ukraine conflict: a product network approach

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Exposure to trade disruptions in case of the Russia-Ukraine conflict: a product network approach

The recent outbreak of the Russia-Ukraine military conflict is expected to affect the world economy through global value chains due to sanctions imposed on the Russian economy and a severe decline in Ukrainian production. This study provides a first-cut analysis of the possible economic impact of this war on third countries. Using product-level export data from international trade statistics, we first identify the most important products exported by Ukraine and Russia. Then, applying a comprehensive indicator of exposure, we measure the dependence of third countries on products imported from Ukraine or Russia, taking into consideration indirect trade connections and the substitutability of imports with domestic production. The results show that Ukraine is dominant in global trade through exporting iron products and agricultural products, while Russia is important through exporting energy sources, raw materials, and iron products. Analysing countries' total exposures, we found that the post-Soviet and European countries have high exposure to Russian imports, confirming the energy dependence of these countries. The Middle East and African countries heavily depend on Ukraine, especially for grain imports, possibly causing food security problems. Finally, the results explain why some European countries hesitate to apply sanctions on Russia in the field of energy sources.

Keywords: international trade, global value chains, Russia-Ukraine war, network analysis, exposure

Introduction

Recent decades have witnessed a significant increase in global trade. While specialization and trade has always been an important channel of economic development, the spatial fragmentation of production activities has led to globally organized supply chains and production networks, which resulted in an increased interconnection of economies (Johnson and Noguera 2012; Baldwin and Lopez-Gonzalez 2015; Wang et al. 2017). A complex system of economic relations emerges from this increased interconnectedness with mutually dependent countries and actors sitting at the nodes of this system.

While this process undoubtedly brings efficiency and provides opportunities for developing countries to get involved in the global division of labour (Cristelli, Tacchella and Pietronero 2015; Straka, Caldarelli, and Saracco 2017), the price that must be paid for these benefits is the systematic risk emerging from the increased interconnectedness (Fang et al. 2020; Iloskics, Sebestyén and Braun 2021; Barrot, Grassi and Sauvagnat 2020; Bonadio et al. 2021; Guan et al. 2020; Sheng 2010; Schweitzer et al. 2009; He and Deem 2010). Through the process of specialization, the nodes and the edges of the global production network become increasingly exposed to certain disruptions, when adjustment of the supply chains requires longer periods of time. As a result of the strong interconnectedness, these disruptions can lead to cascades of shock transmission across countries, even if the disruption is localized (Barrot, Grassi and Sauvagnat 2020; Fang et al. 2020; Guan et al. 2020).

The Covid-19 pandemic illustrated a truly exogenous, but global shock, where countries had to implement restrictions on economic activity in general, almost symmetrically, leading to serious disruptions in supply chains and transportation. Although these restrictions have been released since then, the gradual adjustment and connected price effects are still influencing the economic landscape (Vidya and Prabheesh 2020; Baldwin and Freeman 2020; Barrot, Grassi and Sauvagnat 2020; Guan et al. 2020; Bacchetta et al. 2021; Castañeda-Navarrete and López-Gómez 2020; Simola 2021). A more local, but emblematic episode was the grounding of the Ever Given vessel in the Suez Canal, the estimated cost of which was 40 million USD per hour, considering the hundreds of other ships forced to wait on the sea for days (Lee and Wong 2021). While the Covid-19 pandemic is an example of disruptions in the operation of the nodes of the global production network, thus expected to affect all countries to certain levels, the blocked transportation route by the vessel showcases a disruption at one edge in this complex system and how it affects other parts of it.

The recent war between Russia and Ukraine is another example of such disruptions. In this case, two nodes of the production and supply network are the origin of the causal links of economic consequences. The Russia-Ukraine war has negative impacts on these countries' economic activity for different reasons. In Ukraine, the armed conflict has destroyed the infrastructure, stopped transportation, including international trade, and chased away a significant share of the workforce. In contrast, Russia has found itself in a difficult position through various economic sanctions, such as restrictions on international financial operations, a ban on Russian import and export of certain products in several other countries or breaking the connections of Western companies with the Russian partners and economy.[1]

The present situation is not without antecedents, as in 2014, when Russia annexed Crimea and Sevastopol, the European Union, the United States and some other countries, responded by imposing sanctions against Russia. As a result of the embargo, Cheptea and Gaigné (2020) estimated the loss of the European Union exports to Russia at an average 125 million euro per month. However, exports of the banned products have been redirected from Russia, so total exports of EU have even increased under the Russian embargo.

Based on analyses using CGI models Boulanger et al. (2016) have found similar results, Russia suffered the heaviest losses with an income loss of roughly 3.4 billion euro. This has been accompanied by a significant welfare loss of 1.84% in Russia according to the calculations of Hinz and Monastyrenko (2022). Food prices increased by 7.7%-14.9% in the short term, but prices have remained permanently higher for at least 2 years. This price shock has trickled down to the non-embargo sectors through domestic input and output links (Hinz and Monastyrenko 2022).

These shocks hit international relations directly and strongly in the case of both Russia and Ukraine, which can also lead to supply disruptions in other countries. The position of Russia and Ukraine in the global value chain has long been a subject of interest in the literature. These studies focus on the heavy economic dependence between the two countries on the one hand (Smolansky 1999), and on the energy dependence of the EU on Russia on the other (Laurila 2003).

After the Russia-Ukraine conflict in Crimea, several studies (Güney 2014) drew attention to the risk of the energy dependence of the EU on Russia. However, this dependence is not one-sided. Kuzmenko et al. (2017) examined Russia's dependence on crude oil between 2000 and 2014. According to the study, the Russian economy should focus on export-oriented development based on "non-oil" exports. Despite the recommendation of the study, the role of crude oil exports will remain dominant in the Russian economy.

Bearing these in mind, this study focuses on the extent to which third countries depend on imports from (exports of) Ukraine and Russia within product networks. We provide a first-cut analysis of the potential economic impact of the war between Russia and Ukraine. We build on trade data to estimate the exposure of countries to these economies, which, albeit for different reasons, suffer from the economic consequences of military actions. These economic developments are spread across the globe through intensive trade relations and supply chains, leading to adjustment pressures in the short run and potential restructuring in the long run. This study focuses on the short-term impacts by looking at the relative exposure of countries to these shocks. In this attempt, we rely on commodity trade data, which has at least two advantages over industry-level input-output data. First, instead of the typical aggregation level of world input-output data (e.g., WIOD (Timmer et al. 2015) or ICIO (OECD 2021)), we have a very detailed overview of different commodities and trade. Second, comprehensive input-output datasets are relatively limited in their geographical coverage, most importantly the key countries of the present conflict are not included in either the WIOD or ICIO datasets. Commodity trade data, on the other hand, provides a much broader geographical scope of the data, including these key countries. A clear limitation of commodity trade data is that we miss the fine overlook of input-output datasets on intra-country commodity flows between economic actors. However, we try to compensate for this drawback by using a network approach in the analysis, applied to the commodity-level trade network, which can proxy some aspects of traditional input-output analysis. Also, we point out that relying on commodity trade data at the country level is suitable for tackling the question of short-term exposure and impacts, input-output and computable general equilibrium (CGE) models may provide a better understanding of long-term effects and restructuring of the global economy.

The rest of the paper is structured as follows. Next, we provide an overview of the applied data sources and the methods that we used to filter the relevant commodities and to construct country-specific exposure indices. Then, we present the empirical findings based on this data and methodology, while a further section discusses the results and draws our conclusions from the study.

Data and method

Data

In this study, we rely on international trade statistics provided by the UN Comtrade Database to identify the most important goods exported by Ukraine and Russia on the one hand, and to analyse the dependencies of other countries from the latter two countries on the other. In order to separate the potential effects of the Russia-Ukraine war on global value chains from the structural changes in international trade caused by the COVID-19 pandemic, we use data for 2019, reflecting trade structure in the pre-pandemic period. Along with these principles, we collected product-level trade data for 152 countries, using SITC revision 4 classification at the 4-digit level. This sample of countries accounts for 93.6 percent of total world GDP, thereby covering a significant part of the world economy.[2]

In contrast to aggregated sectoral input-output data, product-level trade data provide an opportunity for a much deeper and focused analysis with a broader coverage of countries. As we have mentioned in the Introduction, multiregional input-output data (for example, WIOD (Timmer et al. 2015) or ICIO tables (OECD 2021)) can provide a basis of more accurate economic analysis through input-output and CGE models, but these tables contain fewer countries, most importantly, data for Ukraine is not available. On the other hand, these databases contain information on sectoral trade flows at a much higher level of aggregation and the key unit of analysis, an aggregated industry may cover very heterogenous sets of commodities both at the input and output sides.

Methodology

This section consists of three different parts. In the first part, we describe the calculation of revealed comparative advantage of Russia and Ukraine based on their export data. This method allows the identification of those products in which these two countries play an important role. In the second step, we define the product-level networks and the measurement of countries' position in these networks. By degree-centrality and eigenvalue-centrality, we can check whether Ukraine or Russia is a central actor in the trade of these identified products. Finally, we introduce a dependency indicator that captures the countries' exposure to Ukrainian and Russian imports.

Revealed Comparative Advantage

Economies export hundreds of different goods and services. Most of them represent a small weight, while few products have a much higher role in the export portfolio. We calculate the role of the products in countries' export by measuring the revealed comparative advantage (RCA) method, proposed by Balassa (1965). In this concept, we compare a product's share within the export portfolio of a given country to this product's share in the entire global trade.

A country has a revealed comparative advantage in a product if it exports this product more intensively than expected, according to world average. We introduce $x_{i,p}$ as the export value of country i in product p, and using this notation, RCA can be defined as

$$RCA_{i,p} = \frac{x_{i,p}}{\sum_p x_{i,p}} \Big/ \frac{\sum_i x_{i,p}}{\sum_{i,p} x_{i,p}}. \quad (1)$$

If $RCA_{i,p} > 1$, country i has revealed comparative advantage in the export of product p, but if $RCA_{i,p} < 1$, it has a revealed comparative disadvantage in terms of this product. Larger values of $RCA_{i,p}$ indicates that country i has a more dominant role in global trade in terms of producing and exporting product p. In a case of a shock, like a lockdown triggered by COVID-19 or a military conflict, this country may have a strong effect on others through international relations, causing product shortages and rising prices. We use this indicator to reveal those products in the global trade Ukraine and Russia play an important role in.

Product networks and the position of countries

Once the relevant products are selected on the basis of RCA, we map the product-level trade networks and examine how central Ukraine and Russia are in these networks. By RCA, we can measure how important a product is in a country's export basket relatively to the world average. In contrast, using different centralities, we can determine how important a country is in the global trade of this product.

These networks are described by the adjacency matrices $\mathbf{W}^p$, where the vertices are the countries and the (weighted) edges are export values of product p. Thus, the general element $w_{ij,p}$ of this matrix shows the value of export in product p going from country i to country j. This network is directed, reflecting that export of country i to country j is different from the export of country j to country i. In what follows, we also refer to the network of export connections in terms of a given product p as network p.

The simplest way to determine the position of a country is to calculate how much it exports to others. Mathematically, it means that we sum the weighted links from this country to others:

$$x_{i,p} = \sum_j w_{ij,p}. \quad (2)$$

In terms of network analysis, $x_{i,p}$ is the out-degree centrality of country i. Similarly, we can also determine the total import, in other words, the in-degree centrality of a country:

$$m_{i,p} = \sum_j w_{ji,p}. \quad (3)$$

Due to the better comparison of countries' positions in different product networks, we normalize the out-degree in the following way:

$$\bar{x}_{i,p} = \frac{x_{i,p}}{max(x_{i,p})}. \quad (4)$$

An advantage of the previous measures is that they are straightforward to calculate and have a clear interpretation: out- and in-degree reflect total exports and imports of product p in case of country i , while normalized out-degree reflects the export share of product p. But these measures only reflect the direct links and do not consider the embeddedness of nodes (countries) within the broader network. However, due to tax optimization, circumventing import and export restrictions and critical transportation routes, products may often reach their destination through an intermediate country (see e.g. Lemmers and Wong 2019; Lau, Chen and Xiong 2017; Ferrantino and Wang 2008; Fisman et al. 2008). In one case, a country may simply re-export the products that it imported from elsewhere, being an intermediate country on a transportation route between the origin and target countries. However, it may also happen that this intermediate country consumes the imported products and exports its own production. In this case, if import drops out, the country can substitute it by reducing its export. For this reason, the origin country from which this intermediary country imports can exert an indirect impact on target countries, which import from the intermediate country. This way or the other, countries' position in the broader product network also depends on these intermediary roles measured by high export volumes between an origin and target country. Because of this, we also apply eigenvector-centrality to detect most central countries. This centrality takes into account the neighbours' position in the network of a country and can be defined as follows (Bonacich 1987):

$$c_{i,p} = \frac{1}{\lambda_p} \sum_j w_{ij,p} c_{j,p}, \qquad (5)$$

where $c_{i,p}$ is the eigenvector-centrality of country i in network p and λ_p is the dominant eigenvalue of matrix $\mathbf{W}^p$. The definition in equation (5) is recursive, and collecting the $c_{i,p}$ centrality scores into the vector c_p, (5) can be written in the matrix form as $c_p \lambda_p = W^p c_p$, which is an eigenvector problem. Solving this problem and choosing the eigenvector c_p corresponding to the dominant (largest) eigenvalue of matrix W^p gives the needed centrality scores. This approach to capture the wider embeddedness of a given node within the whole network is based on the intuition that a node or actor is more central, if it is surrounded by other more central nodes or actors. The same logic is used in other centrality measures like the PageRank centrality (Brin and Page 1998) or the Scimago Journal Rank (SJR) scores. Also, eigenvector centrality as defined in (5) has a close connection to the Leontief-inverse in input-output analysis. The Leontief-inverse matrix represents how a given sector is affected by a demand-side shock in any other sector. The row-sums or row-means of the Leontief inverse matrix thus reflects how a given sector is affected, on average, by demand side shocks. Aldasoro and Angeloni (2015) show that these averages, also known as Rasmussen-Hirschman indices, converge to the eigenvector centrality in the limit. It follows that eigenvector centrality, apart from being a measure of wider embeddedness of nodes within a network, also captures the extent to which these nodes play important roles in the transmission of economic shocks.

In the study, we use eigenvector centrality to support the choice of product categories to be analysed. In addition to revealed comparative advantage and export volume, which reflect the importance of a given product within a specific country's export portfolio, eigenvector centrality reflects the relative importance that this country plays on the global market in terms of a given product category.

Measuring exposure

In the previous subsection, we have shown some methods to measure the countries' position in the trade network as exporters. In the next step, we define an indicator to calculate the total exposure of a given country to another which is determined by several factors.

In the first place, if a country imports a product directly from Ukraine or Russia at a larger extent, then the breakdown of this import relationship is more likely to lead to a shortage of this product within the domestic production activities. We can formalize this direct exposure (DE) of country j from country i in network p as follows:

$$DE_{ij,p} = \frac{w_{ij,p}}{m_{j,p}}, \tag{6}$$

where $m_{j,p}$ is the total import, in other words, the in-degree centrality of country j. If $DE_{ij,p} = 1$, country j imports product p exclusively from country i, but if $DE_{ij,p} = 0$, there is no import links in this direction.

As mentioned earlier, indirect connections can play a crucial role in international trade due to the tax avoidance and transportation hubs (see e.g. Lemmers and Wong 2019; Lau, Chen and Xiong 2017; Ferrantino and Wang 2008; Fisman, Moustakerski, and Wei 2008). This means that a country may also have indirect exposure to another country because it imports a given product through an intermediate actor. This indirect exposure (IE) can be written as follows:

$$IE_{ij,p} = \sum_{k,i\neq k,j\neq k} DE_{ik,p} * e_{k,p} * DE_{kj,p}, \tag{7}$$

where

$$e_{k,p} = \begin{cases} \frac{m_{k,p}}{x_{k,p}}, & if \ \frac{m_{k,p}}{x_{k,p}} \leq 1, \\ 1, & if \ \frac{m_{k,p}}{x_{k,p}} > 1. \end{cases} \tag{8}$$

The first term in the right-hand side of equation (7) denotes the direct exposure of intermediate country k to the origin country i, while the third term shows the direct exposure of the target country j to intermediate country k. The second term, $e_{k,p}$ shows the ratio of the intermediate country's import and export of the product. If the export volume is larger than its import, this intermediate country produces a large part of the export itself, which reduces the exposure of the target country on the origin country. This indirect exposure is $IE_{ij,p} = 1$ if the target country j imports a product p exclusively from intermediate country k and the latter imports the same product exclusively from origin country i, while the intermediate country is a net importer of this product. Also, this must be true for all possible intermediate countries. Indirect exposure is $IE_{ij,p} = 0$, if any of the terms in equation (7) is zero, i.e. either the target country is independent of the intermediate country k, or the latter is independent of the origin country i in terms of importing product p, or the intermediate country does not import this product at all. Also, this must be true for all possible intermediate countries.

This formulation also draws attention to the third factor of exposure. Countries have the opportunity to mitigate the effect of disruptions in imports from Ukraine or Russia by constraining their own export of these products, thus still satisfying domestic demand.[3] In this context, we assume that imports of product p can be replaced by exports of the same product category. This assumption is supported by the relatively detailed disaggregation level of product categories (4 -digit SITC) that we use in the analysis which ensures a relatively close substitutability on the import and export sides. However, potential significant quality differences may hinder this substitutability, but we do not have information on this. The intuition behind the formulation in (7) and (8) is that exposure may be low even if the direct and indirect exposure is high, but the country can replace imports through reducing its exports of the same product. Based on this, we define the substitutability of imports (SI) with exports as follows:

$$SI_{ij,p} = \begin{cases} \frac{x_{j,p}}{m_{j,p}}, & if\ \frac{x_{j,p}}{m_{j,p}} \leq 1, \\ 1, & if\ \frac{x_{j,p}}{m_{j,p}} > 1, \end{cases} \tag{9}$$

where the numerator reflects the out-degree of country i, while the denominator is the in-degree.

Finally, the total exposure of country j on country i can be written as

$$TE_{ij,p} = \begin{cases} DE_{ij,p} + IE_{ij,p} - SI_{ij,p}, & if\ DE_{ij,p} + IE_{ij,p} > SI_{ij,p}, \\ 0, & if\ DE_{ij,p} + IE_{ij,p} < SI_{ij,p}. \end{cases} \tag{10}$$

Using this exposure indicator, we can measure how countries depend on Russia and Ukraine in the product networks, taking into account direct and indirect relations, and the substitutability of imports by exports.

Empirical analysis

In this section, we first identify the most important export products of Ukraine and Russia, then measure how central these countries are in the product-level networks. In the second part, we present the extent to which third countries are dependent on imports from Ukraine and Russia, also illustrating the role of indirect exposure and the substitutability of imports with exports of the same product. At the end of the section, we show the role of indirect trade relations and the substitutability of imports through two different examples.

Product selection

According to the international trade statistics provided by the UN Comtrade database, Ukraine exported 948 different products in 2019, while Russia exported 1002. We calculate the revealed comparative advantage (RCA) for all products in both countries as in equation (1). These calculations show that Ukraine has revealed comparative advantage (i.e. $RCA > 1$) in the production of 190 goods, while Russia is shown to have revealed comparative advantage in 133 goods. Considering this high number of products, we restrict further analysis on third countries' exposure to trade with Ukraine and Russia only to the most important products exported by these two countries. As a starting point, we select five-five products in both countries which have the highest RCA score. This corresponds to approximately 0.5% of all exported products. As a second step, we ordered the export products of the two countries according to their volumes (exports in USD). Naturally, these products also have high RCA values, although not necessarily in the top five. In the third step, we choose the union of these two sets of top five products (RCA and export volume) as the relevant product portfolios for the two countries respectively.

Applying these selection methods, we found seven different products in the case of Ukraine, and ten in the case of Russia. As expected, Ukraine is dominant in global value chains mainly through exporting iron products and agricultural products, such as wheat and maize. An interesting result is that Ukraine is the largest exporter of typewriter machines in the world market and the RCA of this product for Ukraine is 328.10. However, its export value is negligible, 579 US dollars, and because of its low importance, we do not examine the network of this product in more detail. In contrast, Russia has a comparative advantage primarily in raw materials and energy sources, such as asbestos, anthracite, and pig-iron, and it sells the most from crude oil, mineral oil, and natural gas on the world market. The export value of not classified special transactions is the third largest in Russian export at more than 58 billion US dollars. The reason is that natural gas transported via pipelines appears in this product category.[4] It is important to note that this category also contains other transactions, so we cannot purely measure the countries' total exposure in terms of natural gas, especially in the case of Central Eastern European Countries. We found two of the relevant products (pig-iron and semi-finished products of iron (> 0.25% carbon)) that are among the most important export products for both countries. These relevant products are shown in Table 1 and 2.

Thus, in the next step, we examine the trade network of these 15 different products, and measure how central Ukraine and Russia are in the networks. These product networks are plotted in Figures 1-3, where the red and yellow dots indicate Russia and Ukraine respectively, all other countries are grey, and the size of the vertices reflects the countries' normalized out-degree centrality ($\overline{x}_{i,p}$, according to equation (4)). The main property of these networks is that their density and the number of dominant actors vary in a wide range. For example, there is only one country (Russia) which exports asbestos to a large extent on the global market, and only a few countries trade with this because most countries banned this product for health reasons. On the other hand, the network of flat-rolled products of iron being denser and there are multiple dominant exporting countries. These structural properties point out that shocks, like a war or a natural disaster, can have a more intense impact on the rest of the world if these shocks hit one of the most dominant countries. Especially in those cases, where the number of dominant countries is fewer, or the network is denser.

The results also show that Ukraine or Russia has central positions in these networks, confirming that the export of these countries is globally relevant in terms of the given products. For instance, Ukraine is the world leader in the export of sunflower oil, while

Russia is first in the trade of asbestos, anthracite, crude petroleum, different products of iron, and nuclear reactors and parts. If we also consider the indirect trade relations through calculating eigenvector-centrality ($c_{i,p}$, according to equation (5)), Ukraine and Russia are still shown to be central in these networks. On the other hand, we also find that in some cases, such as crude petroleum or wheat, their eigenvector-centrality is lower than their normalized out-degree, and they are also ranked lower. It means that their partners do not export as much as the partners of the other countries, and their partners play a less important role as intermediate country towards the rest of the world.

Analysing the export structure of Ukraine and Russia, we found that both countries have strong comparative advantage in the cases of pig-iron and semi-finished products of iron (>0.25% carbon). In addition, their centralities also suggest that both countries are among the largest and most influential exporters in the global market. On the other hand, wheat, semi-finished products of iron (<0.25% carbon), and sunflower oil have a prominent role in the Ukrainian export portfolio as shown by the export volume and RCA values, while the importance of these products within the Russian export structure is not so prominent. Nonetheless, the centralities of both countries are among the highest values in these product networks. For these 5 products, thus, the effects of the Russia-Ukraine war on global trade might be exceptionally strong.

Countries' exposures

We calculated the total exposure of the 152 countries in the dataset to Ukraine and Russia respectively, according to equation (10). This results in a TE value for every country-pair, which are depicted in Figure 4, where shades towards red reflect higher and shades towards white reflect lower exposure. Third countries in the rows and product categories in the columns are ordered according to their average TE value. In the case of Russia, the average total exposure of all other countries is largest in anthracite, followed by asbestos and mostly energy sources, like coal and crude petroleum. The average total exposure towards Ukraine is outstanding in sunflower oil, followed by different types of iron, and other agricultural products. Iron materials provide an interesting case, as both Ukraine and Russia are large exporters of all listed types (see their networks Figures 1-3). As centrality in product networks already indicated, countries' average exposure towards Russia is stronger than towards Ukraine.

Among all the countries, Armenia (0.50 average TE), Belarus (0.42) and Moldova (0.34) as being post-Soviet countries, have the largest average exposure to Ukrainian and Russian imports of the listed products. These numbers are extremely high, considering that there are some listed products in which these countries have 0 exposure. These three countries are also the most exposed considering solely Russian imports. Generally, all post-Soviet countries are very exposed to Russia, with some nearby European countries like Finland (0.44 average Russian TE), Bulgaria (0.36), Slovakia (0.35) and Hungary (0.31) also having considerable exposure. If we consider only Ukrainian exposure, interestingly Costa Rica (0.41 average Ukrainian TE) comes out as the most exposed. Otherwise, mostly Middle Eastern and African countries: Jordan (0.38), Israel (0.34), Tunisia (0.33), Ethiopia (0.29), Lebanon (0.26) are on the top of the list.

Generally, it is assumed that countries are exposed through a certain product if they have a non-zero TE in that product, while the level of exposure depends on the value of TE. This way, Figure 4 also reveals that all countries in the world are exposed to Ukraine and Russia to a certain extent. There are some South American, Caribbean, Oceanian and South African countries that are only exposed through 2 or 3 products. The rest of the world is generally exposed through 5+ products. Despite taking own export volumes into account via SI, large countries are still not protected. For example, China and India both have an average of 0.2 TE, which are among the largest average exposures. There are some countries with their whole import of a certain product coming from solely Russia or Ukraine. These are mainly post-Soviet countries, but there are other examples, like the whole Bulgarian import of nuclear reactors and parts, and the whole Lebanese and Albanian other coal arrive from Russia, while more than 90% of sunflower oil import in Bermuda, Guyana, and Costa Rica arrives from Ukraine.

Some territorial patterns are already visible in Figure 4, but to make them even clearer Figure 5 displays the average total exposure of each geographic region. It is noticeable, although hardly surprising, that post-Soviet countries are largely exposed to Russian trade in all of the listed products, but not particularly to Ukrainian trade, except for flat-rolled products of iron. Europe, even without the post-Soviet area, is also heavily exposed to Russia mainly through energy sources: natural gas, crude petroleum, and particularly coal imports (anthracite and other coal). Russian imports of other raw materials like asbestos and types of iron are less important for Europe. However, Europe is considerably exposed to Ukraine through different types of iron materials and maize. Patterns are different in the exposure of Asia, as there are three outstanding products in which Asia, on average, is heavily exposed, namely anthracite, asbestos and sunflower oil. American and Oceanian countries are much less exposed to the Russian energy sources than the rest of the world, which can be explained to a large extent by their geographical distance and other accessible energy source supplies. The only remarkable exposure here is through Ukrainian sunflower oil. Interestingly, African economies are much more exposed to Ukraine than Russia through the listed products, mainly due to considerable exposure to agricultural imports like sunflower oil, maize, and wheat.

The total exposure of each country consists of three elements as shown in equation (10). Figure 6 shows the decomposition of total exposure in two important products: crude petroleum from Russia, and sunflower oil from Ukraine. Among the 20 biggest crude petroleum importers, 15 have some exposure to Russia. Most of these countries do not export the product at all, so instead of re-exporting, they are final users of crude petroleum. Only the USA, Australia, the UK, and Canada can benefit from being major exporters themselves. Direct exposure (ratio of Russian imports) is the main driver behind the countries in close geographical proximity having the largest TE, namely Belarus, Finland, Poland, and Turkey.

The decomposition of total exposure to Ukrainian sunflower oil is much more mixed. India and China with the largest total exposures only have direct exposure, and no re-export. Some other countries, like Spain, Malaysia and the Netherlands also have considerable direct exposure, but they are major re-exporters, so substitutability comes into effect. Indirect exposure is also significant in some – mostly western – countries, like the United Kingdom, Belgium, Germany, the USA, and France. This indicates that these countries import large amounts of sunflower oil from re-exporter countries. For example, 46.1% of the German import arrives from the Netherlands, while the Netherlands imports 55.9% of their sunflower oil from Ukraine, also being among the largest exporters in the world. This way Netherlands is an important intermediary actor between Ukraine and Germany.

The decomposition also reveals that trade patterns and the resulting exposures are very different across products. In the trade of crude petroleum re-exporting is not common, as most large importers utilize their imported amount for final use. While in the trade of sunflower oil it is common that a country is a major importer and exporter at the same time. This trade pattern results in a much denser product trade network than one that does not involve re-exporting to a large extent, as visible in Figures 1-3. Therefore, for products with denser trade networks indirect exposure is important to be considered.

Discussion

In this study, we provided a first-cut analysis of the possible impact of the Russia-Ukraine conflict on global value chains. In the first step, we examined the export structure of both countries and identified the key export products for both countries. Then, we measured how central the two countries are in these relevant product networks. Finally, using an exposure indicator, we determined the exposure of other countries to Ukrainian or Russian export, considering the indirect relations and substitutability of imports.

The results show that the post-Soviet countries have the highest exposure to Russia, but European countries, especially East-Central European countries, also depend on Russian imports heavily. The main difference between them is that post-Soviet countries do not impose any economic sanctions on Russia, but the EU members apply strict restrictions on financial operations and trade. Thus, despite their higher exposure, post-Soviet countries may be less adversely affected by the direct economic consequences of the war. On the other hand, the results confirm the high exposure of the European countries to energy sources exported by Russia (Paillard 2010; Casier 2011; Krickovic 2015, Liuhto 2015), which can provide an explanation for why these countries, such as Hungary or Slovakia, do not support import restrictions on energy sources. The results also indicates that the dependence of the USA on Russian imports, especially for energy sources, is much smaller than for the European countries. It suggests that the restrictions applied by the USA can have a lower impact on both economies than those by the EU. In addition, it is important to note that the application of sanctions is a double-edged sword because these have negative impacts on both parties, such as in 2014 (Cheptea and Gaigné 2020; Hinz and Monastyrenko 2022).

In many developing countries, such as in Pacific Islands (Barnett 2011), Asia (Kim, Kim and Park 2020), or Middle Easters and African countries (Sadler and Magnan 2011), preserving food security remains a problem because they are not self-sufficient and need to import several types of staple food. However, the cultivation and import of grains are significantly affected by weather and climate conditions (Barnett 2011, Sadler and Magnan 2011), pest infestations (Sadler and Magnan 2011), and restrictions on exports and imports, for example, triggered by COVID-19 (Kim, Kim and Park 2020; Mohamed et al. 2021). Our findings suggest that the Russia-Ukraine war can also result in food security problems in certain countries because Ukraine is one of the largest grain exporters on the global market (Vasylkovska et al. 2021), and several countries have high exposure to Ukrainian imports. Egypt is a typical example of this situation because it has a significant import exposure to grains such as wheat, and Ukraine is the largest partner for Egypt (Veninga and Ihle 2018). On the other hand, because Russia is also an important grain-exporter country, the applied sanctions against it can further exacerbate the food security problems through even higher price increases and transportation difficulties. Finally, it is also important to note that falling Ukrainian and Russian grains exports could raise product prices which can have a global impact, not just on some heavily dependent countries.

Several industries, such as the construction, automotive industry, and manufacturing machinery, use different products of iron in production processes as input. Meanwhile, the analysis of these products networks reveals that Ukraine and Russia are central actors as exporters of iron materials on the global market. Many countries (e.g., Armenia, United Arab Emirates, Greece, Bulgaria) have high exposure to Ukraine, and others (e.g., post-soviet countries, Finland, Jordan, Turkey) to Russia. Due to the war, the EU banned iron and steel products imported from Russia, and the stoppage of production in Ukraine could lead to a decrease in imports of these products. Consequently, there can be a shortage of iron and steel materials used in production, which can turn to supply problems and price increases at higher stages of the value chains.

Some countries seem to be heavily affected by the economic consequences of the war through direct relations, but the results also show that indirect relations and re-exports also influence countries' total exposures. The products often reach their destination through an intermediary country due to tax optimization, circumvention of import and export restrictions, and transportation routes (see e.g. Lemmers and Wong 2019; Lau, Chen and Xiong 2017;

Ferrantino and Wang 2008; Fisman, Moustakerski and Wei 2008). For instance, 54 % of the total export of the Netherlands comes from imports (Lemmers and Wong 2019). It also emerges from our results, that the Netherlands is an important intermediary actor in the network of several products between the initial countries (Ukraine, Russia) and many target countries. Overall, this pattern draws attention to the effects of indirect links in the shock propagation processes that were also observable in the case of Brexit (Vandenbussche, Connell, and Simons 2022), the US-China trade war (Mao and Görg 2020; Wu et al. 2021), or COVID-19 (Giammetti et al. 2020).

In this study, we examined the countries' exposure only through trade relations which can be a primary indicator of the possible shortage of products in large amounts exported by Russia and Ukraine on the global market, especially in the short term. However, other economic factors can influence the impacts of this war on the global economy. In our analysis, we do not consider the effects on price, the possible other import sources, and the substitutability of a product by other products. Furthermore, we did not use an input-output or general equilibrium model to estimate the welfare losses of the countries triggered by the war due to the availability of data and the coverage of the country. These methods would provide a different approach to estimate of possible economic impacts.

Footnotes

1. See e.g. the article of Kowsmann and Talley (2022), and Stiff (2022) in Wall Street Journal, and Blenkinsop et al. (2022) reports in Reuters.
2. For this calculation, we collected data from World Bank (https://data.worldbank.org/). The data were available for 148 countries from selected 152 countries in 2019.
3. For example, the Hungarian government announced to ban all grain export due to curbing price raises (Reuters 2022). Another example for banning export is Egypt (Safty and Lewis 2022) which imports wheat from Ukraine (and Russia) at a high ratio.
4. According to the data provided by international trade statistics (UN Comtrade Database), Russia does not export liquified natural gas to Hungary on code 3431 of the SITC revision 4. classification. However, the Hungarian Central Statistical Office shows that Hungary exported

natural and other gas in more than 1.5 billion US dollars in 2019, which is approximately equal to the value of special transactions from Russia to Hungary (https://statinfo.ksh.hu/Statinfo/haViewer.jsp?lang=en).

Disclosure of financial interest

The authors declare that they have no competing interests.

Additional information

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Data availability

All data can be downloaded free of charge online from UN Comtrade Database: https://comtrade.un.org/data/.

References

Aldasoro, I., and I. Angeloni. 2015. Input-output-based measures of systemic importance. *Quantitative Finance* 15(4): 589-606. doi: https://doi.org/10.1080/14697688.2014.968194.

Bacchetta, M., E. Bekkers, R. Piermartini, S. Rubinova, V. Stolzenburg, and A. Xu. 2021. COVID-19 and global value chains: A discussion of arguments on value chain organization and the role of the WTO, *WTO Staff Working Paper*, No. ERSD-2021-3. doi: http://dx.doi.org/10.30875/40db0106-en.

Balassa, B. 1965. Trade liberalization and "revealed" comparative advantage. *Manchester School of Economic and Social Studies* 33(2): 99-123. doi: https://doi.org/10.1111/j.1467-9957.1965.tb00050.x.

Baldwin R., R. Freeman. 2020. Supply chain contagion waves: Thinking ahead on manufacturing contagion and reinfection' from the covid concussion. Accessed March 28, 2022. https://voxeu.org/article/covid-concussion-and-supply-chain-contagion-waves.

Baldwin. R., and J. Lopez-Gonzalez. 2015. Supply-chain trade: A portrait of global patterns and several testable hypotheses. *The World Economy*. 38(11):1682{1721. doi:https://doi.org/10.1111/twec.12189.

Barnett, J. 2011. Dangerous climate change in the Pacific Islands: food production and food security. *Regional Environmental Change* 11:229-237. doi: https://doi.org/10.1007/s10113-010-0160-2.

Barrot, J.-N., B. Grassi, and J. Sauvagnat. 2020. Sectoral effects of social distancing. Technical Report IN-2020-1371, HEC Paris. https://doi.org/10.2139/ssrn.3569446.

Blenkinsop, P., S. Siebold, M. Strauss, and F. Guarascio. 2022. EU to ban steel imports from Russia, luxury goods exports to Moscow. *Reuters*, March 11. Accessed March 28, 2022. https://www.reuters.com/markets/europe/eu-unveils-fourth-set-sanctions-against-russia-2022-03-11/.

Bonacich, P. 1987. Power and centrality: A family of measures. *American Journal of Sociology* 92 (5):1170-1182., doi: https://doi.org/10.1086/228631.

Bonadio, B., Z. Huo, A. A. Levchenko, and N. Pandalai-Nayar. 2021. Global supply chains in the pandemic. *Journal of International Economics*, page 103534. Accessed March 28, 2022. https://ideas.repec.org/p/nbr/nberwo/27224.html.

Boulanger, P., H. Dudu, E. Ferrari, and G. Philippidis. 2016. Russian roulette at the trade table: a specific factors CGE analysis of an agri-food import ban. *Journal of Agricultural Economics*, 67(2), 272-291. doi: https://doi.org/10.1111/1477-9552.12156

Brin, S., and L. Page. 1998. The anatomy of a large-scale hypertextual web search engine. *Computer Networks and ISDN Systems* 30(1-7): 107-117. doi: https://doi.org/10.1016/s0169-7552(98)00110-x.

Casier, T. 2011. The rise of energy to the top of the EU-Russia agenda: from interdependence to dependence? *Geopolitics*, 16(3), 536-552. https://doi.org/10.1080/14650045.2011.520862.

Castañeda-Navarrete, J., J. Hauge, and C. López-Gómez. 2020. COVID-19's impacts on global value chains, as seen in the apparel industry. Development Policy Review, 39(6), 953-970. https://doi.org/10.1111/dpr.12539.

Cheptea, A., and C. Gaigné. 2020. Russian food embargo and the lost trade. European Review of Agricultural Economics, 47(2), 684-718. doi: https://doi.org/10.1093/erae/jbz032.

Cristelli M., A. Tacchella, and L. Pietronero. 2015. The Heterogeneous Dynamics of Economic Complexity. *PLoS ONE* 10(2): e0117174. pmid:25671312. https://doi.org/10.1371/journal.pone.0117174.

Fang, H., C. Ge, H. Huang, and H. Li. 2020. Pandemics, global supply chains, and local labor demand: Evidence from 100 million posted jobs in China. *Technical Report* 28072, National Bureau of Economic Research. https://doi.org/10.3386/w28072.

Ferrantino, M. J., and Z. Wang. 2008. Accounting for discrepancies in bilateral trade: The case of China, Hong Kong, and the United States. *China Economic Review* 19(3):502-520. https://doi.org/10.1016/j.chieco.2008.02.002.

Fisman, R., P. Moustakerski, and S-J. Wei. 2008. Outsourcing tariff evasion: a new explanation for entrepôt trade. *The Review of Economics and Statistics* 90(3): 587-592. doi: https://doi.org/10.1162/rest.90.3.587.

Giammetti, R., L. Papi, D. Teobaldelli, and D. Ticchi. 2020. The Italian value chain in the pandemic: the input-output impact of covid-19 lockdown. *Journal of Industrial and Business Economics* 47(3): 483-497. https://doi.org/10.1007/s40812-020-00164-9.

Guan, D., D. Wang, S. Hallegatte, S.J. Davis, J. Huo, S. Li, Y. Bai, T. Lei, Q. Xue, D. Coffman, et al. 2020. Global supply-chain effects of covid-19 control measures. *Nature Human Behaviour*, 4:577–587. https://doi.org/10.1038/s41562-020-0896-8.

Güney, N. A. 2014. Where does the EU stand in energy dependence on Russia after the Ukrainian crisis: are there any alternatives at hand? Perceptions: *Journal of International Affairs*, 19(3), 15-34. https://dergipark.org.tr/en/pub/perception/issue/48964/624638

He, J., and M. W. Deem. 2010. Structure and response in the world trade network. *Physical review letters*, 105(19), 198701. https://doi.org/10.1103/PhysRevLett.105.198701.

Hinz, J., E. Monastyrenko. 2022. Bearing the cost of politics: Consumer prices and welfare in Russia. Journal of International Economics, 137, 103581. https://doi.org/10.1016/j.jinteco.2022.103581.

Iloskics, Z., T. Sebestyén, and E. Braun. 2021. Shock propagation channels behind the global economic contagion network. The role of economic sectors and the direction of trade. PLOS ONE 16(10): e0258309. https://doi.org/10.1371/journal.pone.0258309.

Johnson, R. C., and G. Noguera. 2012. Accounting for intermediates: Production sharing and trade in value added. *Journal of international Economics* 86(2):224-236. https://doi.org/10.1016/j.jinteco.2011.10.003.

Kim, K., S. Kim, and C-Y. Park. 2020. Food Security in Asia and the Pacific amid the COVID-19 Pandemic. *ADB Briefs* 139. http://dx.doi.org/10.22617/BRF200176-2.

Kowsmann, P., I. Talley. 2022. What is shift and why is it being used to sanction Russia? *The Wall Street Journal*, March 1. Accessed March 28, 2022. https://www.wsj.com/articles/swift-banking-system-sanctions-biden-11645745909?mod=article_inline.

Kuzmenko, E., L. Smutka, M. Pankov, and N. Efimova. 2017. The success of economic policies in Russia: Dependence on crude oil Vs. Export diversification. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*, 65(1), 299-310. https://doi.org/10.11118/actaun201765010299.

Krickovic, A. 2015. When Interdependence Produces Conflict: EU–Russia Energy Relations as a Security Dilemma. *Contemporary Security Policy*, 36(1), 3–26. https://10.1080/13523260.2015.1012350.

Lau, L. J., X. K. Chen, and Y.Y. Xiong. 2017. Adjusted China-US trade balance. Lau Chor Tak Institute of Global Economics and Finance, the Chinese University of Hong Kong, *Working Paper 54*. Available at http://www.igef.cuhk.edu.hk/igef_media/working-paper/IGEF/igef%20working%20paper%20no.%2054%20english%20version.pdf.

Laurila, J. 2003. Transit transport between the European Union and Russia in light of Russian geopolitics and economics. *Emerging Markets Finance and Trade*, 39(5), 27-57. https://doi.org/10.1080/1540496X.2003.11052553.

Lee, J. M. Y., and E. Y. C. Wong. 2021. Suez Canal blockage: an analysis of legal impact, risks and liabilities to the global supply chain. *In MATEC Web of Conferences (Vol. 339). EDP Sciences*. https://doi.org/10.1051/matecconf/202133901019.

Lemmers, O., and K.F. Wong. 2019. Distinguishing between imports for domestic use and for re-exports: a novel method illustrated for the Netherlands. *National Institute Economic Review* 249(1): R59-R67. https://doi.org/10.1177/002795011924900115.

Liuhto, K. 2015. The economic dependence of EU member states on Russia. *The War in Ukraine: Lessons for Europe, 78*.

Mao, H., and H. Görg. 2020. Friends like this: The impact of the US-China trade war on global value chains. *The World Economy* 43(7):1776-1791. https://doi.org/10.1111/twec.12967.

Mohamed, E. M. A., S. M. A. Abdallah, A. Ahmadi, and III. D.E. Lucero-Prisno 2021. Food security and COVID-19 in Africa: implications and recommendations. *The American*

Journal of Tropical Medicine and Hygiene 104(5):1613-1615. https://doi.org/10.4269/ajtmh.20-1590.

Paillard, C. A. 2010. Russia and Europe's mutual energy dependence. *Journal of international affairs*, 63(2), 65-84. http://www.jstor.org/stable/24384335.

Sadler, M., and N. Magnan. 2011. Grain import dependency in the MENA region: risk management options. *Food Security* 3:77-89. https://doi.org/10.1007/s12571-010-0095-y.

Safty, S. E., and A. Lewis. 2022. Egyptians count rising bread costs as Ukraine war disrupts wheat exports. *Reuters*, Mach 17. Accessed March 28, 2022. https://www.reuters.com/world/africa/egyptians-count-rising-bread-costs-ukraine-war-disrupts-wheat-exports-2022-03-17/.

Schweitzer F., G. Fagiolo, D. Sornette, F. Vega-Redondo, A. Vespignani, R. D. White 2009. Economic Networks: The New Challenges. *Science.* 325:422–425. pmid:19628858. https://doi.org/10.1126/science.1173644.

Sheng A. 2010. Globalization and Growth Implications for a Post-Crisis World. In: Spence M, Leipziger D, editors. Financial crisis and global governance: A network analysis. Washington DC: World Bank; p. 69–93.

Simola, H. 2021. The impact of Covid-19 on global value chains. http://urn.fi/URN:NBN:fi:bof-202101141046.

Stiff, P. 2022. From Apple to McDonald’s, what companies have pulled back from Russia? *The Wall Street Journal*, March 23. Accessed March 28, 2022. https://www.wsj.com/articles/what-companies-have-pulled-back-from-russia-11646425481?mod=article_inline.

Smolansky, O. M. 1999. Fuel, credit, and trade: Ukraine’s economic dependence on Russia. *Problems of Post-Communism*, 46(2), 49-58. https://doi.org/10.1080/10758216.1999.11655828.

Straka M.J., G. Caldarelli, F. Saracco. 2017. Grand canonical validation of the bipartite international trade network. *Phys. Rev. E.* 96:022306. pmid:28950577. https://doi.org/10.1103/PhysRevE.96.022306.

Reuters. 2022. Hungary to ban all grain exports effective immediately – agriculture minister. *Reuters*, March 4. Accessed March 28, 2022. https://www.reuters.com/article/ukraine-crisis-hungary-grains-idAFL5N2V75IT.

Timmer, M. P., E. Dietzenbacher, B. Los, R. Stehrer, and G. J. de Vries. 2015. An illustrated user guide to the World Input-Output Database: the case of global automotive production. *Review of International Economics* 23(3): 575-605.https://doi.org/10.1111/roie.12178.

Vandenbussche, H., W. Connell, and W. Simons. (2022). Global value chains, trade shocks and jobs: An application to Brexit. *The World Economy* 0:1-32. https://doi.org/10.1111/twec.13259.

Vasylkovska, K., O. Andriienko, O. Vasylkovskyi, A. Andriienko, P. Volodymyr, and V. Malakhovska. 2021. Dynamics of export potential of sunflower oil in Ukraine. *Helia*, 44(74), 115-123. https://doi.org/10.1515/helia-2021-0001

Vidya C., and K. Prabheesh. 2020. Implications of covid-19 pandemic on the global trade networks. *Emerging Markets Finance and Trade* 56(10):2408-2421, https://doi.org/10.1080/1540496x.2020.1785426.

Veninga, W., and R. Ihle. 2018. Import vulnerability in the Middle East: effects of the Arab spring on Egyptian wheat trade. *Food Security* 10:183-194. doi: https://doi.org/10.1007/s12571-017-0755-2.

Wang Z., S.J. Wei, X. Yu, and K. Zhu. 2017. Characterizing global value chains: Production length and upstreamness. *Tech. rep., National Bureau of Economic Research*, https://doi.org/10.3386/w23261.

Wu, J., J. Wood, K. Oh, and H. Jang. 2021. Evaluating the cumulative impact of the US-China trade war along global value chains. The World Economy 44(12): 3516-3533. https://doi.org/10.1111/twec.13125.

OECD. 2021. *OECD Inter-Country Input-Output Database*. http://oe.cd/icio.

Table 1. The most important products in Ukrainian export according to RCA and export volume.

Rank	SITC 4-digit code	Name of product	RCA	Total export (in thousand US $)
Top 5 products by RCA				
1	7511	Typewriters	328.10	0.58
2	4215	Sunflower seed oil	136.58	4 273 473.81
3	6712	Pig-iron	70.40	801 834.21
4	0449	Other maize, unmilled	56.92	5 209 733.99
5	6727	Semi-fin. products of iron (> 0.25% carbon)	53.35	596 089.91
Top 5 products by total export				
1	0449	Other maize, unmilled	56.92	5 209 733.99
2	4215	Sunflower seed oil	136.58	4 273 473.81
3	0412	Other wheat	35.17	3 655 172.71
4	6726	Semi-fin. products of iron (< 0.25% carbon)	46.43	2 263 914.28
5	6732	Flat-rolled products of iron	15.53	1 952 098.04

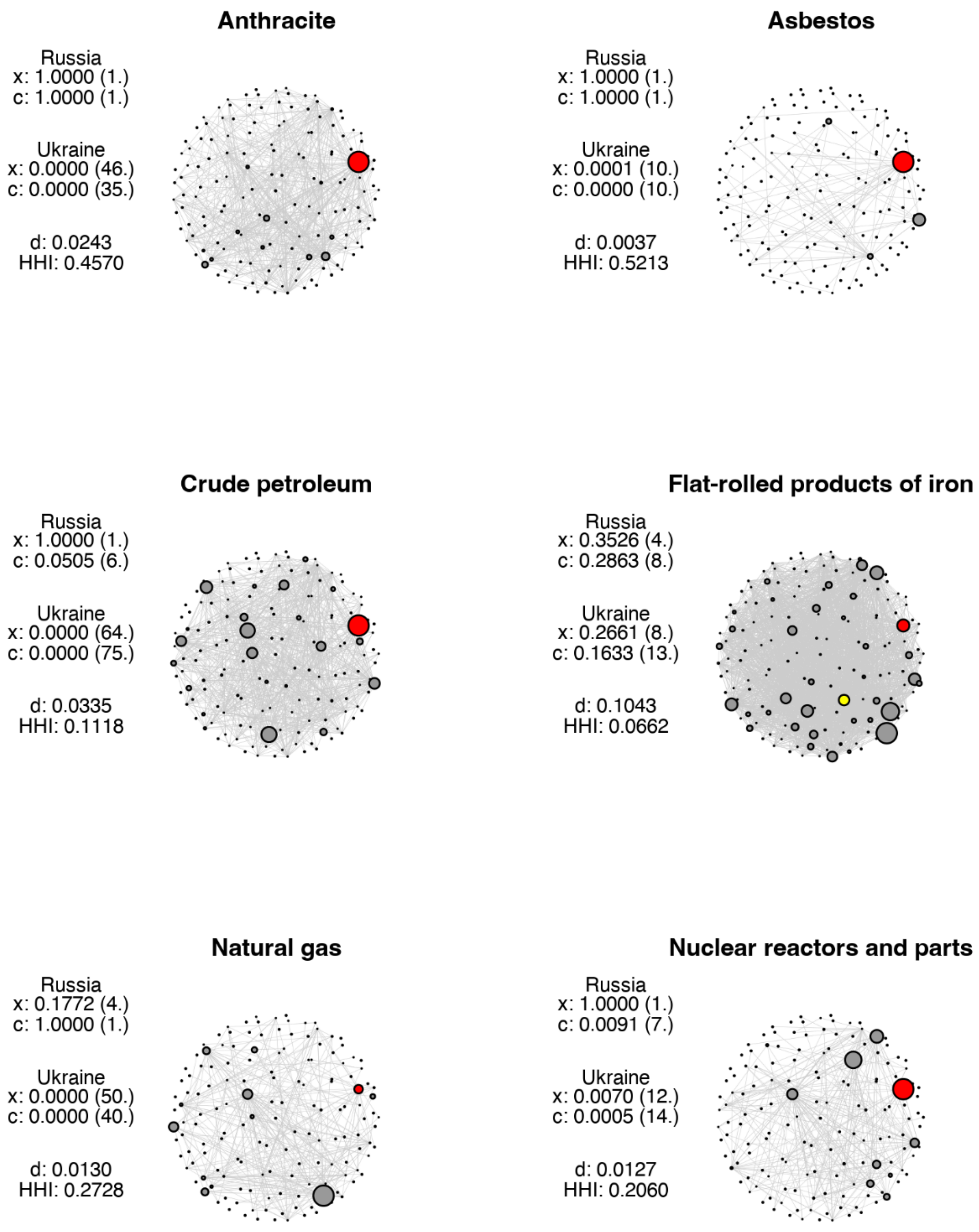
The values of revealed comparative advantage (RCA) are calculated according to equation (1).

Table 2. The most important products in Russian export according to RCA and export volume.

Rank	SITC 4-digit code	Name of product	RCA	Total export (in thousand US $)
TOP 5 products by RCA				
1	2784	Asbestos	28.52	187 936.53
2	3211	Anthracite	27.55	2 354 086.25
3	6712	Pig-iron	14.82	1 440 816.22
4	7187	Nuclear reactors and parts	13.99	889 573.21
5	6727	Semi-fin. products of iron (> 0.25% carbon)	13.65	1 301 379.31
Top 5 products by total export				
1	3330	Crude petroleum	7.15	122 228 578.65
2	3346	Petroleum oils	4.10	66 946 527.97
3	9310	Special transactions (not classified)	2.20	58 314 876.12
4	3212	Other coal	5.28	13 632 532.88
5	3431	Natural gas, liquefied	3.61	7 920 048.41

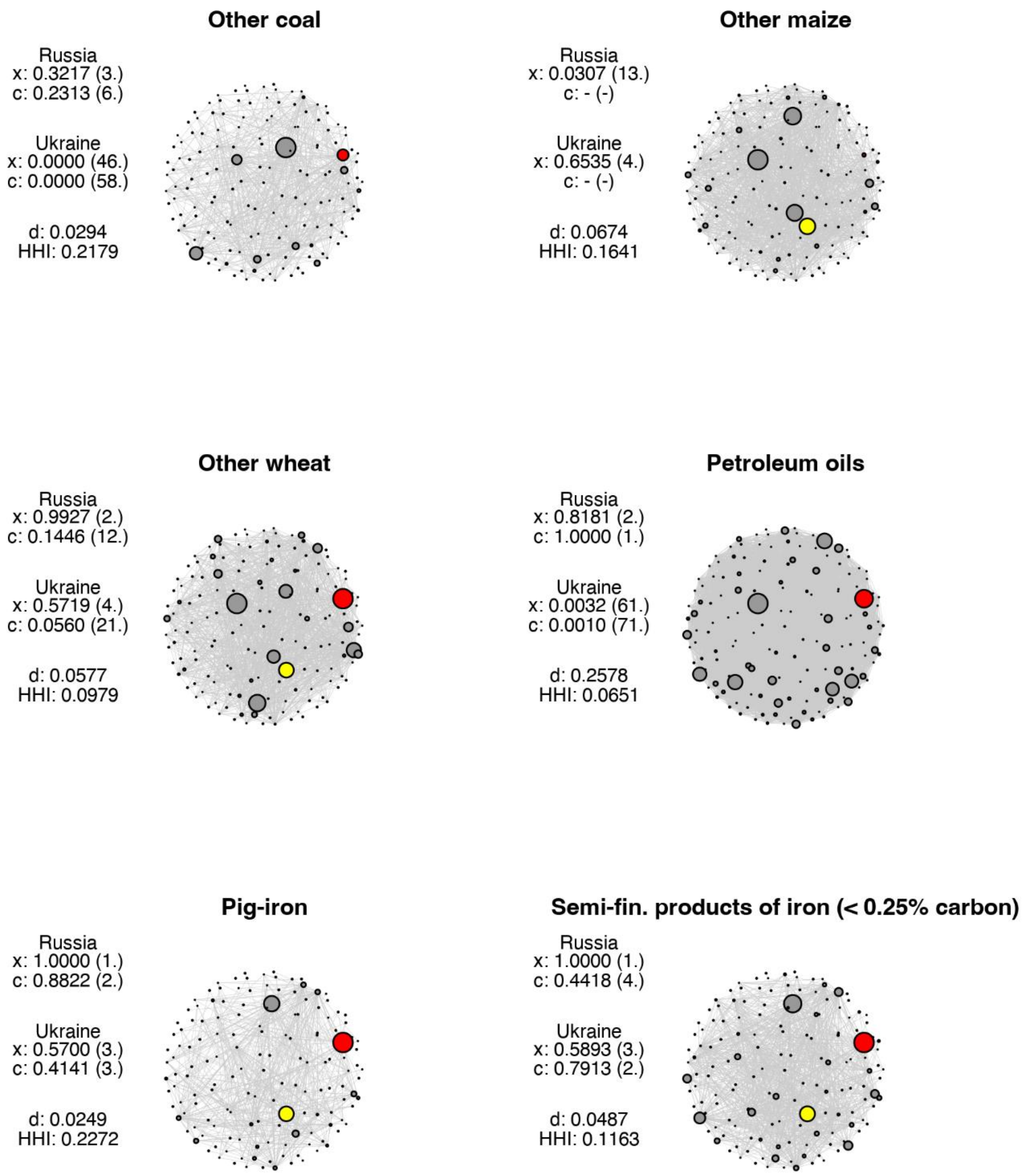
The values of revealed comparative advantage (RCA) are calculated according to equation (1).

Figure 1: The trade networks – Part I.



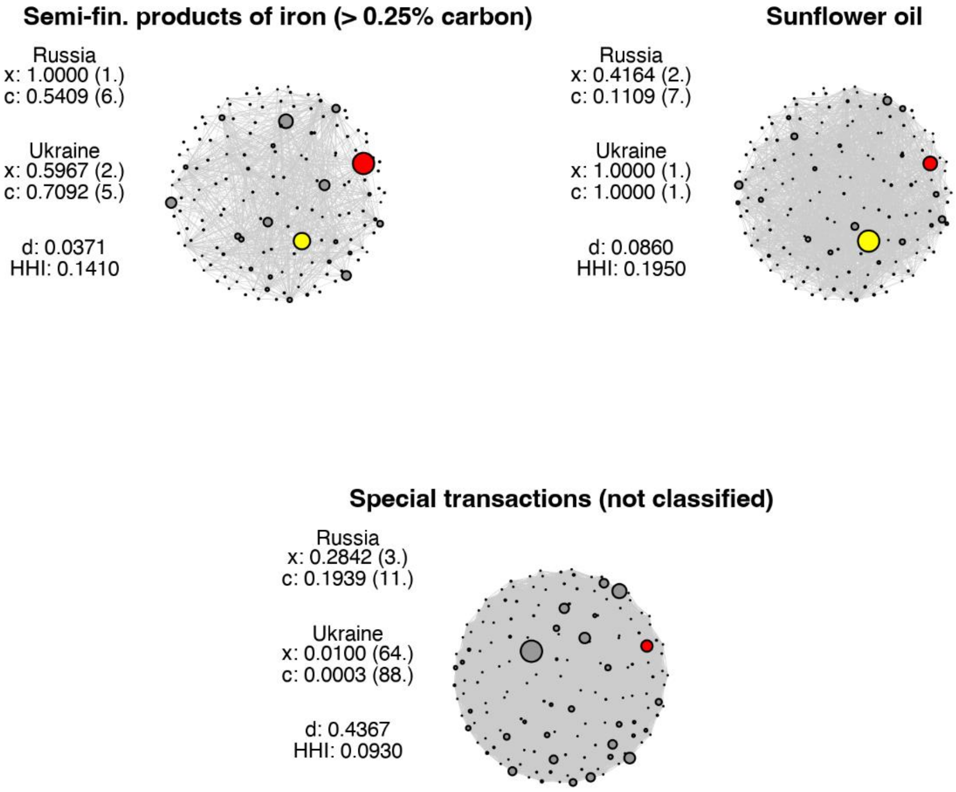
The red and yellow vertices indicate Russia and Ukraine respectively, all other countries are gray. The size of the vertices reflects the country's normalized out-degree centrality $\overline{x}_{i,p}$, according to equation (4) - square root of the original values are used for proper visualization. The panels show the normalized out-degree centrality ($\overline{x}_{i,p}$), the eigenvector-centrality ($c_{i,p}$, according to equation (5)) for Russia and Ukraine, as well as their rank in the respective rankings (in parentheses). The panels also contain information about the density of the network (d) and the concentration of exports (out-degree centrality) by Herfindahl-Hirschman-index (HHI).

Figure 2: The products network – Part II.



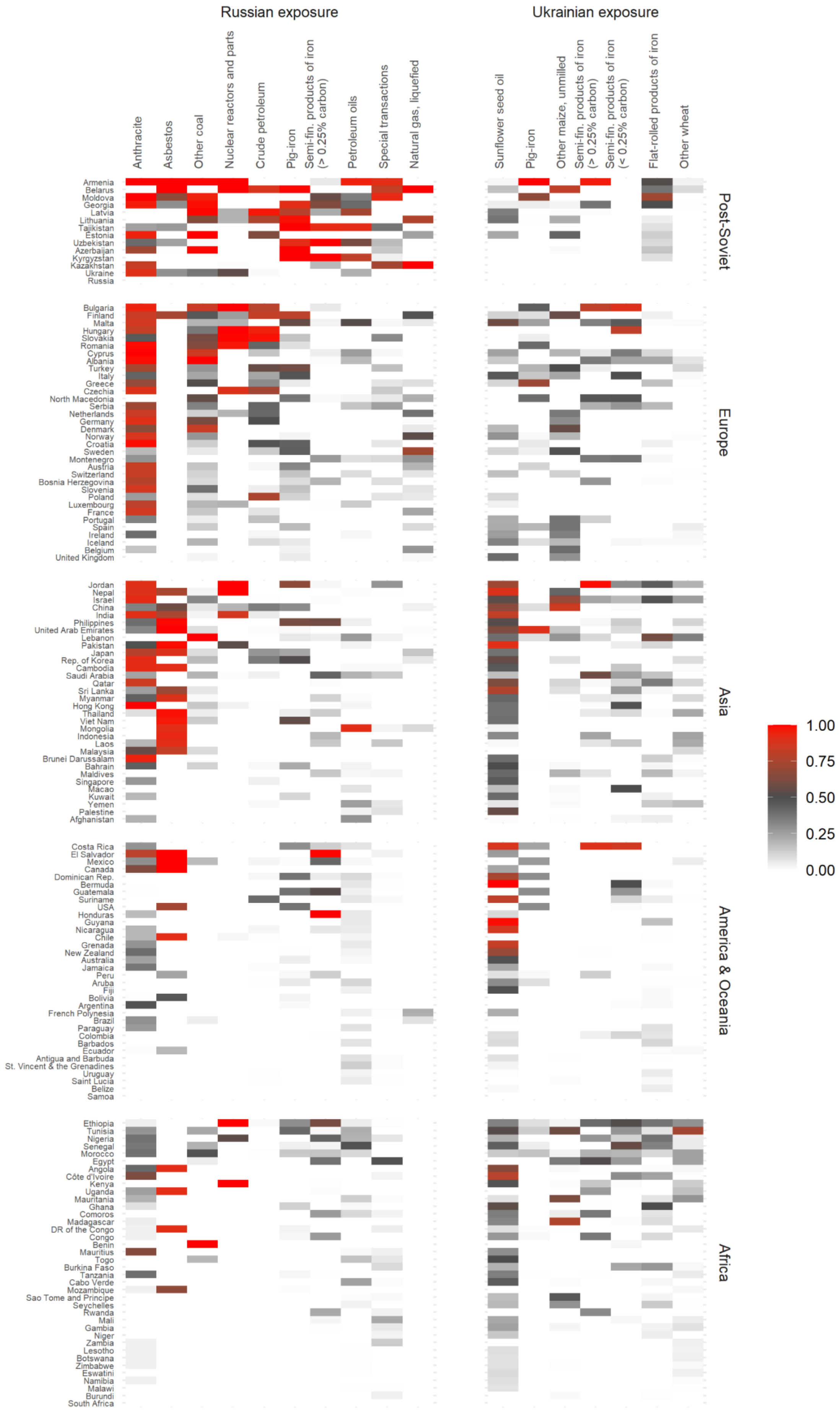
The red and yellow vertices indicate Russia and Ukraine respectively, all other countries are gray. The size of the vertices reflects the country's normalized out-degree centrality $\bar{x}_{i,p}$, according to equation (4) - square root of the original values are used for proper visualization. The panels show the normalized out-degree centrality ($\bar{x}_{i,p}$), the eigenvector-centrality ($c_{i,p}$, according to equation (5)) for Russia and Ukraine, as well as their rank in the respective rankings (in parentheses). The panels also contain information about the density of the network (d) and the concentration of exports (out-degree centrality) by Herfindahl-Hirschman-index (HHI).

Figure 3: The products network – Part III.



The red and yellow vertices indicate Russia and Ukraine respectively, all other countries are gray. The size of the vertices reflects the country's normalized out-degree centrality $\bar{x}_{i,p}$, according to equation (4) - square root of the original values are used for proper visualization. The panels show the normalized out-degree centrality ($\bar{x}_{i,p}$), the eigenvector-centrality ($c_{i,p}$, according to equation (5)) for Russia and Ukraine, as well as their rank in the respective rankings (in parentheses). The panels also contain information about the density of the network (d) and the concentration of exports (out-degree centrality) by Herfindahl-Hirschman-index (HHI).

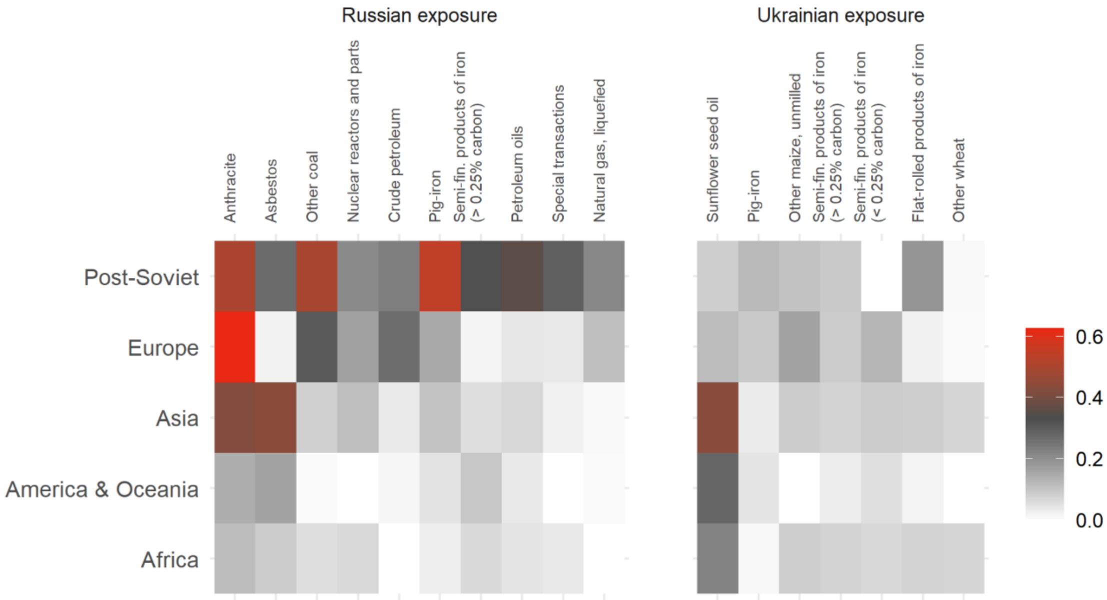
Figure 4: Total exposure of all countries based on selected products



Russian exposure
Ukrainian exposure
Anthracite
Asbestos
Other coal
Nuclear reactors and parts
Crude petroleum
Pig-iron
Semi-fin. products of iron (> 0.25% carbon)
Petroleum oils
Special transactions
Natural gas, liquefied
Sunflower seed oil
Pig-iron
Other maize, unmilled
Semi-fin. products of iron (> 0.25% carbon)
Semi-fin. products of iron (< 0.25% carbon)
Flat-rolled products of iron
Other wheat
Post-Soviet
Europe
Asia
America & Oceania
Africa
1.00
0.75
0.50
0.25
0.00

Within each territory, countries are ranked according to their average total exposure.

Figure 5: Average total exposure of each territory based on selected products



In the calculation of average total exposure each country was treated with equal weights.

Figure 6: Breakdown of total exposure (TE) in two important products (top 20 countries in import volume displayed)