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SPATIAL IMPACT OF COVID-19 IN TURKEY

Global supply and demand of medical ventilators in the fight against Covid-19: a network analysis

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Abstract

As global value chains have taken shape, the geographic concentration of production in specific centers or hubs to minimize production costs is an issue that has been raised following the onset of the Covid-19 pandemic. The criticism typically highlights how the production capacity within these global value chains is insufficient to meet the global needs for medical equipment and devices in this type of crisis. This study uses complex network analysis to examine the global trade structure of surgical masks and medical ventilators and its general patterns. The findings of this study conducted between 2019 and 2020 show that this trade structure has complex network properties and a core-periphery structure. A comparative evaluation of the results from these 2 years also reveals the economic fragility of the ventilator trade network even if it is easier to adapt urgent conditions in mask trade. In addition, according to the network analysis and the authority centrality values for 2020 the fact that the highest-ranked countries for ventilator imports are almost exclusively developed countries suggests that the trade structure might also indicate a moral deterioration. In sum, the empirical findings confirm that the structure of the current global value chains will not be immune to supply shocks during emergencies such as a pandemic.

Keywords Public health · Medical goods trade · Global value chains · Pandemic · Laissez faire system · Global supply and demand for medical goods

JEL Classification F1 · H75 · I14 · I18

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1 Introduction

Mainstream economic theory regarding international economic relations, which has been traced historically from D. Ricardo to P. Samuelson, is based on three premises: (i) markets are perfectly competitive and producers work with constant returns to scale, (ii) industry consists of homogeneous producers, (iii) countries only trade in final products and each product is produced using only the production factors of the exporting countries (Inomata 2017). However, as criticism of these premises emerged, new types of foreign trade theories began to appear. The first premise was criticised with the development of the "New Trade Theory" between 1970 and 1980. Instead of constant returns to scale, this school observed that production technology has increasing returns to scale. As a result, this led them to propose instead that international trade takes place under imperfect competitive conditions. These new models offered a more comprehensive explanation for the prevalence of intra-industry trade between countries with similar technology and resources, which could not be explained by the orthodox approach. The second premise was uprooted as a result of research conducted in the late 1990s. Later changes in information and communication technologies and transportation methods allowed for each stage of production to be divided into separate sub-divisions. Each of these subdivisions was located across different geographical regions that turned out to be more efficient in the production process. The third premise of the classical theory was quite limited in its ability to explain the recent trade dynamics of intermediate goods and the ways it has increased. This type of trade distribution, which includes commerce across international borders, was found to involve not only final products but also intermediate goods (Inomata 2017). The explanations regarding this third premise are directly related to the concept of Global Value Chains (GVCs) and the ways it operates. Therefore, much of the current international trade literature develops an understanding of these processes in a way that incorporates the realities of GVCs.

As the concept of GVCs first emerged, the notion of a "commodity chain" became a point of research toward the end of the 1970s. This concept referred to the entire set of production inputs and operations that were used to generate a final product. Later, in the mid-1990s, the concept of a "global commodity chain" was put forward. This concept was similarly used to trace the production process from the raw material stage to the final product. However, it was in the 2000s when the commercial and industrial structures began to be reframed as an international value-added chain or "global value chain". More recently, there has been a new emphasis on using the concept of a 'network' rather than a 'chain' to describe these economic structures. The basic premise of this new emphasis is that economic activities are based on very complex interactions between global producers (De Backer and Miroudot 2014). In fact, globalisation has not only led to a quantitative increase in international economic activities in this sense but also brought a qualitative change. Within the scope of GVC-related research, many have advanced a concept called a "global production network" (GPN) (Milberg and Winkler 2013) which highlights the relationship of large multinational companies in industrialised countries with a complex supply network in the rest of the world.

In the search for greater efficiency and higher profits, multinational companies have established GVCs that are now well embedded in the global economic infrastructure. Similar to many other products, the production process of medical equipment and devices was developed within this structure. As the demand for these devices increased during the Covid-19 pandemic, the concentration of the production in certain geographical areas caused many supply-level limitations as the demand was increasing. Specifically, the separation of the various stages of production created major obstacles for the supply of intermediate goods within the process. Therefore, this study seeks to closely examine the context of the global trade network used to produce surgical masks and medical ventilators and to observe the fragility of this trade structure in the framework of GVCs. In the next section of the study, observations related to the failure of free markets and laissez-faire policy during the Covid-19 pandemic are assessed. This is followed by a summary of studies on the production and trade of these products, an outline of the method and the analysis, and finally a summary and evaluation of the empirical results.

2 Failure of GVCs and laissez-faire policies in the Covid-19 era

The importance of GVCs in macroeconomic development especially for developing countries has continued to evolve because participation in the global economy contributes significantly to a country's overall economic advancement. However, the level of development is also closely related to a country's role within the GVC. Moreover, the various components of trade and investment are additional factors that connect countries to GVCs (Gereffi 2015).

In addition to its positive contribution to economic growth, it is a fact that GVCs have increased the economic fragility level in certain contexts. The most well-known example of this was during the 2008 global financial crisis. During the crisis, the decline in the GDP of many countries was not only more pronounced than in previous crises, but its rate of decline was much more accelerated. The synchronised collapse of trade was largely due to the globalisation of the supply chain which led to a simultaneous collapse in the economic output of various interconnected countries. It is understood that the GVCs formed the structure for these connections and had an important effect on the speed and extent of the economic collapse. The GVCs accelerated the spread of the crisis from the US financial markets to the financial markets of other countries and, in a short time, all the sectors of the global economy were severely impacted. As decreases in demand for final goods quickly affected the flow of intermediate goods, the entire chain was affected. Thus, the GVCs, functioning like a channel, allowed the financial shocks in 2008 to spread rapidly into the global economy. (Milberg and Winkler 2013).

However, the criticisms are not only limited to how GVCs and their structures have produced a level the economic fragility. The effects of the pandemic show that the structure of GVCs, which were initially created under the laissez-faire economic policies of the 1980s and became globally institutionalised with the WTO, could not effectively meet the production needs at one of the most critical moments. As the cases first appeared in 2020, the demand for products such as test kits, medicines,

personal protective equipment and ventilators to combat the virus significantly increased on a global scale. However, for many countries around the world, the supply of these vital products, used both for protection against infection and for the treatment of infected patients, was insufficient. The ensuing struggle to access these essential medical products varied from export bans among exporting countries to removing tariffs on imports for countries in urgent need of importing these products. In addition, the various closures of global ports and disruptions in the logistics process also prevented the demand for these vital products from being met (Vickers et al. 2020). Trade organisations intervened by encouraging exporting countries to lift these types of restrictions and bans. However, this response was too limited and failed to see the source of the problem. The main problem was the market system that prevented the production of these goods in sufficient quantity. The measures taken in response, therefore, did not provide a genuine solution to the supply shortage. Even an aggressive increase in production remained insufficient to meet the 20-fold increase in demand (Gertz 2020). Baltzan (2020) mentions that during the pandemic this supply problem has two main sources. The first is that production is concentrated in a small number of countries. A failure or breakdown in one of these countries, where production is highly concentrated and contains important links in the supply chain, will negatively and sharply affect the other links in the chain. The most well-known example of this situation is the concentration of mask production in China. At the beginning of the pandemic, there were serious difficulties in accessing masks on a global scale. However, this problem did not persist for long since many countries were able to develop production solutions fairly quickly for producing their own medical masks, which is a relatively simple product. Nonetheless, there is another deeper and more systemic problem with respect to this lack of capacity. This problem becomes particularly felt in the production of more advanced technological equipment such as medical ventilators for Covid-19 patients in intensive care. The source of this inadequate capacity is an economic system that prioritises efficiency, characterised by low costs, against flexibility and strength in overall production. Efficiency mentioned here means having a production capacity to meet the demand in 'normal' times. However, in emergencies or crises, the system requires additional capacity that is not readily available within this economic structure. Baltzan (2020) explains that this economic system did not occur spontaneously, but it was a result of intentional decisions and policies that would remove the state from the market. According to these policies, the state's role was to ensure the conditions necessary for the protection of property rights with minimal intervention. Based on the neoliberal policies of the 1980s, governments have framed a structure for businesses and international commerce that encourage them to prioritise and pursue low costs and higher profits. After 1990, these policies took on a more global character through the formation of an intricate trade system with specific trade agreements. The framework for global production within this trade system emphasized the importance of low-cost/high-profit production. Globalisation and international commerce developed inside this structure as it was particularly promoted by the WTO. This system allowed capital to move freely and even encouraged developing economies to try to attract capital, while the benefits to the labor sector were quite limited. The global competition to attract capital put pressure on state regulations that aimed

to protect society, labor and the environment. Multinational corporations, whose priority is profit maximisation, were also attracted by lower costs in the judicial system of developing countries. Production turned out to be concentrated in many countries where the judicial system is flexible and cost-effective, and this concentration has been observed to be a consequence of the laissez-faire economic system (Baltzan 2020). Drezner (2001) also explains how this situation developed in what is called the 'Race to the Bottom Theory' (RBT). According to this theory, the mobility of trade and capital flow creates policy pressures on countries that turn to practices that are contrary to these market forces since capital inevitably looks for locations where it can gain the highest return. More specifically, high corporate taxes, strict labor laws and strict environmental protection measures will increase production costs and reduce profitability; thus, the system encourages capital to flow toward the countries with the lowest regulatory standards. In other words, the RBT predicts that: (i) the more open a country is to global markets, the more its tax and regulatory policies will converge toward the countries that maintain international openness, (ii) there is a negative correlation between the level of incoming capital and regulatory standards, (iii) the countries that apply the most thorough-going laissez-faire policies will be the most attractive (Drezner 2001). This trajectory of public policy removes the obstacles that hinder the formation of GVCs (Nie 2016).

Baltzan (2020) draws attention to the distinction between a laissez-faire system and free enterprise. From this perspective, free enterprise focuses on the development and maintenance of the competitive market and includes government intervention as needed. On the other hand, the laissez-faire system is based on the absence of government intervention, even if it is to protect competition. Therefore, the laissez-faire system, according to Baltzan, is compatible with unequal competition and the system's continuity tends toward a concentration of industrial monopolies, maltreatment of the workforce and harm to the environment. One of the observed outcomes of this entire process was that since the supply chains were geographically concentrated in areas where firms can maximise their profits, the nature of the supply chains weakened the ability of many governments to respond effectively to the pandemic (Baltzan 2020). Another outcome of this system is observed in the US, in which the government refrained from intervention in markets for medical goods. However, this policy resulted in chaos since the market mechanism could not allocate the supply and demand of these goods. Willingness to pay was so high while the ability to pay is low for a vast majority of the population. Thus, the allocation of medical goods by market mechanism did not align with public interest (Gertz 2020). This is what makes us consider about the laissez-faire system and the health policies applied by the governments. Wang (2021) states that urgent deepening reforms in healthcare, industrial policy, welfare distribution and labour markets have become inevitable in the post-covid period. The reason is that protecting their citizens during a crisis is the primary duty of governments. In other words, avoiding a repeat of shortages of medical supplies in the future is expressed as the primary aim of governments (Evenett 2021). The pandemic has made us recognize this top policy priority of governments. It has been understood that authorities with a well-prepared public health infrastructure are less engaged in panic buying and less inductive for panic buying of the citizens. As stated by Evenett (2021), in the absence of a robust

supply response of medical goods, demand surges accelerated by panic buying makes shortages inescapable (Evenett 2021).

Putting all these together, the importance of the preparedness of governments against such emergencies should be emphasized. Preparedness against such emergencies is closely related to awareness of current GVCs' weaknesses and reshaping the public policies. Hence, in the following part, we summarize some studies related to the trade of mask and ventilator and the sufficiency of policies implemented by countries.

3 A brief review of the literature

First, it should be noted that there is not much empirical study on the trade of surgical masks in the literature due to a lack of sufficient data reachability. In their empirical study, Hayawaka and Imai (2022) examined the trade of medical products among 35 reporting countries and 250 partner countries for January–August period in both 2019 and 2020. Their findings revealed that the burden stemming from the pandemic causes decreases in the export of medical products. However, this decrease changes depending on the partner country. If there are political and economic ties or neighbourhood with these countries, then the decrease is lower. When it comes to importing, identities and demographic ties have a key role.

Specific studies regarding the trade of medical ventilators during the Covid-19 pandemic also have not yet surfaced in the literature. Most of the studies are situation analyses from a statistical perspective. In one of these studies, Evenett (2020) refers to export restrictions imposed on basic medical products and equipment during the pandemic, emphasizing how these ventilators are a life-or-death issue for patients struggling with Covid-19. Referring to the importance of the international supply chain for the mechanical parts of this type of technological product, Evenett stresses the troubling issues that export bans created for this product and its component parts. According to UN statistics, as of 2018, there are no countries that are exporting ventilators in Africa, South Asia, the CIS (Commonwealth of Independent States) region and the Middle East. Mehrotra et al. (2020), in a study where they model the ventilator supply chain according to a stochastic optimisation model, examine the process of its allocation and sharing during the pandemic. The findings of this study analysed the optimal distribution of medical ventilators among the US states by FEMA (Federal Emergency Management Agency). The analysis showed that if less than 60% of the ventilator inventory is available for non-Covid patients, FEMA's 20,000 ventilator stock is almost sufficient to meet the anticipated needs. However, when more than 75% of the existing inventory is reserved for non-Covid patients, various degrees of deficiencies are expected. Similarly, Ranney et al. (2020) developed some suggestions as a result of their evaluation during the period shortly after the announcement of Covid-19 as a pandemic, when there was a shortage of access to ventilators. The first of these suggestions was that the US federal government's guidance for companies producing ventilators to maximise their production would not be sufficient. They also suggested that access to the necessary raw materials should be streamlined and that the federal government needs to effectively

mobilise other industries towards ventilator production. Sutter et al. (2020) stated that the Chinese government nationalised the control of the production and distribution of medical products in February 2020, and in this context, the authority was transferred from the Ministry of Information Industries and Technology (MIIT) to the National Development and Reform Commission (NDRC), which is China's most powerful central economic planning ministry. The NRDC began governing medical manufacturing and logistics at the factory level and directed all the production of medical equipment for domestic use, including the production lines for US companies in China. This nationalisation policy quickly cut off the supply chain of many countries that relied on open and free access to the markets for their medical products. The calculations from the data that was received from China Customs and the Global Trade Atlas revealed that between February 2019 and February 2020, China's ventilator exports decreased by 20%, while its imports from abroad increased by 174%. The WTO (2020) states that the supply of respiratory devices, including the ventilator, is provided by a small number of countries such as Singapore which has an 18% market share, the US 16%, and the Netherlands and China with a 10% market share.

From the literature review, there is no empirical study that examines the ventilator trade on a global scale. To fill this gap in the literature, this study explores the global trade network of medical ventilators using a complex network approach. A complex network analysis enhances the benefits of the study as it is an approach that allows for holistic inferences with advanced indicators regarding the structure of global trade and the bilateral features that exist between the countries. Before mentioning the empirical findings, the following section includes explanations about the study method.

4 Complex network methodology and data

As stated by Reichardt (2009), the first step in understanding a complex system is breaking down the system into its component parts. Contrary to standard approaches, complexity science understands economics as a complex network or system. A network is defined as a set of nodes and a set of links that connect the nodes. Mathematical notation of a network is as follows (Estrada 2015):

$$G = (V, E, f),$$

where V is the set of finite nodes, E is the set of links among these nodes and f is the mapping that connects the elements of E and V. Networks are classified as binary or weighted and also as directed or undirected, depending on the properties of their links (Chow 2013). A weighted network corresponds to a network in which each link has a different weight. The mathematical notation of a weighted network is as follows:

$$G = (V, W, f),$$

where $W = \{w_1, w_2, \ldots, w_m\}$ indicates the set of weights. Degree and strength are important concepts in binary and weighted networks, respectively. The degree of a node is the number of links that node has and the strength of a node refers to the total weight of that node (Chow 2013). The mathematical tool that makes it possible to analyse a network is called a matrix. The following matrix is called an adjacency matrix and is constructed for a binary network (Estrada 2015):

$$A_{ij} = \begin{cases} 1 & \text{if } i,j \in E \\ 0 & \text{otherwise.} \end{cases}$$

An important factor that must be taken into consideration to build an adjacency matrix is the direction of the relation for directed networks and the weight of the relation for weighted networks.

Network analysis has two related but distinct methods (Bougheas and Kirman 2014). One of them is examining the statistics related to the topological properties of the network and the other method is the simulations based on these statistical properties.

There are some major properties examined under the umbrella of what is called topological properties. One of them is connectedness which can be analysed both at the node level and at the network level. In a directed network, which does not involve self-loops and multilinks, connectedness is measured on a network level by a coefficient called a 'density coefficient'. It is expressed mathematically as follows (Newman 2010):

$$\rho = \frac{m}{n(n-1)},$$

where m corresponds to the number of links and n corresponds to the number of nodes. This coefficient indicates the ratio of the number of actual links in the network to the number of maximum possible links. The density coefficient is expressed between 0 and 1. In other words, the higher the coefficient is, the higher the connectedness.

Another important property of a network is reciprocity which can represent a lot of important phenomena. Reciprocity indicates the tendency of node pairs to be connected by mutual links pointing in opposite directions (Ruzzenenti 2010). It is the proportion of mutual connections in a directed graph (Igraph 2021).

Another important topological property is the degree of distribution in a network. A large number of studies based on real-world networks have indicated that there are a lot of nodes with weak links and there are a few nodes with strong links. The shape of this distribution in a logarithmic scale is a straight line. It means that the distribution follows a power-law relationship. A power-law distribution is expressed mathematically as $P(k) \propto k^{-\alpha}$ and it implies that the formation of the links in the network is not random. This is important since this distribution indicates that the network system is controlled by a few hubs with a high level of degree/strength. Even though the number of hubs might be limited, they can determine the behavior of the entire system (Newman 2008). In network theory, a network that follows a power-law distribution is called a scale-free network since the same functional form exists when

the variable is rescaled (Boccaletti et al. 2006). α has a unique importance in a network analysis since a higher α value leads to a lower probability of nodes with many links. In other words, the higher the value of α, the lower the number of super-nodes within the network (Hein et al. 2006).

Power-law distribution has a higher peak and a heavy-tail. One method to determine whether a distribution is heavy-tailed or not is by calculating the kurtosis and also the skewness values. If the kurtosis value is positive, then the distribution has a heavy-tail (Decarlo 1997). Whereas, skewness is a measure to determine on which side of the distribution a heavy-tail might exist. If skewness is positive, then a heavy-tail is on the right side, meaning that the distribution is right-skewed. If skewness is negative, then the distribution is left-skewed (Lovric 2010). However, it is also required to analyse statistically how well a distribution corresponds to the power-law distribution. One of the tests used for this purpose is the Kolmogorov–Smirnov test. If the p value is lower than 0.05, then the null hypothesis that represents its correspondence to the power-law distribution is rejected (R igraph manual pages 2021). Clauset (2011) states that correspondence to the power-law distribution indicates the complexity in the generation process of the structure examined.

Another related property of a network is assortativity/disassortativity. Assortativity implies that nodes with high degree/strength tend to have links with the other nodes that also have high degree/strength. Conversely, disassortativity means that nodes with high degree/strength have a tendency to have links with the nodes that have low degree/strength (Reichardt 2009). A correlation coefficient is used to determine whether an assortative or disassortative structure exists in a network (Newman 2021). This coefficient has a range of $-1 < r < 1$. If it is positive, then there exists assortativity in the network. However, if it is negative, then there exists disassortativity. $r = -1$ corresponds to perfect disassortativity, while $r = 1$ corresponds to perfect assortativity. Detecting an assortative/disassortative structure is an important part of a network analysis since disassortativity can confirm the existence of a core–periphery structure in a network (Fuge et al. 2013: 6; Csermely 2013). In a core–periphery structure, nodes in the core are related to each other and also to nodes in the periphery. However, nodes in the periphery are not related to one another (Borgatti and Everett 1999). Borgatti and Everett (1999) developed a correlation coefficient that measures how well a real-world network corresponds to a network that has an ideal core–periphery structure. This correlation coefficient lies between 0 and 1. The closer to 1 the coefficient is, the closer the real-data network is to a perfect core–periphery structure (Borgatti and Everett 1999). The existence of a core–periphery structure requires the analysis to determine the core and periphery nodes of the network. For this reason, a centrality assessment becomes an important tool for this purpose.

There are a great number of centrality measurements used to determine the weight and prominence of nodes in a network such as a degree centrality, betweenness centrality, closeness centrality, eigenvector centrality, hub and authority centrality. This study uses the hub and authority centralities developed by Kleinberg (1999). In a directed network, a hub is a node with high out-going degree/strength and an authority is a node with high incoming degree/strength. However, Kleinberg states that it is not sufficient for a node to have high out-going degree/strength to be

a 'good' hub; it is also required for this node to have links with 'good' authorities that have high incoming degree/strength. Similarly, a 'good' authority is a node with incoming degree/strength from 'good' hubs. In this way, Kleinberg argues, there is a 'mutually reinforcing relationship' between hubs and authorities (Kleinberg 1999). Kleinberg expresses this relationship as follows:

$$x^{\langle p \rangle} \leftarrow \sum_{q:(q,p)\in E} y^{\langle q \rangle}$$

$$y^{\langle p \rangle} \leftarrow \sum_{q:(p,q)\in E} x^{\langle q \rangle}$$

where $x^{\langle p \rangle}$ and $y^{\langle p \rangle}$ are the weight of the authority and the weight of the hub for node p, respectively. Kleinberg developed an algorithm that works through an iterative process to calculate the hub and authority centralities of the nodes in the network. Each node in the network is assigned a hub and authority centrality value at the end of this iterative process.

Kleinberg first defined the y vector which consists of $y^{\langle p \rangle}$ values and the x vector which consists of $x^{\langle p \rangle}$ values by referencing $G=(V, E)$ where the node vector is $V=\{p_1, p_2, \ldots, p_n\}$. Then, Kleinberg proved that these vectors converge to y^* and x^* at the end of the iterative process. The y^* vector is the hub centrality vector and the x^* vector is the authority centrality vector. Concerning the A matrix that is the adjacency matrix of graph G, the x^* and y^* vectors are eigenvectors of the $\boldsymbol{A}^{\mathbf{T}}\boldsymbol{A}$ and $\boldsymbol{A}\boldsymbol{A}^{\mathbf{T}}$ matrices, respectively (Kleinberg 1999). Thus, $\boldsymbol{M}_{\mathbf{auth}} = \boldsymbol{A}^{\mathbf{T}}\boldsymbol{A}$ and $\boldsymbol{M}_{\mathbf{hub}} = \boldsymbol{A}\boldsymbol{A}^{\mathbf{T}}$ are authority and hub matrices, respectively (Kolaczyk 2009).

Following this methodology, the research design is based on a complex network analysis via adjacency matrices. These matrices are created using data on bilateral exports of masks and medical ventilators from various countries on a global scale. Data from 2019 and 2020 were obtained from the United Nations Comtrade database. The mask product is included under HS17 classification as 630790 and the ventilator product is included under the HS17 classification as 901920. This product group also is defined by the World Customs Organization as a group of respirators and includes the ventilator in the HS classification reference that is used for Covid-19 medical treatment (WCO 2020). Although the Covid-19 virus emerged at the end of 2019, it first became a global threat at the beginning of 2020. For this reason, this study analyses the data and the changes from 2020 by making a comparison with the 2019 data.

5 Empirical results

Here we give the results both on a global scale and for Turkey separately. The results for the global scale include some descriptive network statistics and some properties specific to complex networks while the results on the country scale focus on centrality measures of Turkey.

5.1 Empirical results for global network

First, some descriptions of the network statistics are presented in Table 1. Accordingly, it is seen that there are a total of 208 countries that have participated in the international trade of surgical mask in both years (The country list can be found in Appendix 5). The number of trade connections increased from 6254 to 7353 within the period. However, the number of trade connections for ventilators between these countries decreased from 3221 in 2019 to 2003 in 2020. This difference between the trade of masks and ventilators can be understood as the effect of restrictions imposed on ventilator exports due to the pandemic and also the facility of increasing production easily for the mask. This change in trade is also indicated by the density coefficient. The density coefficient is defined as the share of the number of existing connections in the network with respect to the highest possible number of connections. In our analysis, the density coefficient for ventilator decreased from approximately 8% in 2019 to approximately 5% in 2020 while the density coefficient for mask increased from approximately 15% in 2019 to 17% in 2020.

Although not included in the table, we also observed that the number of exporting countries for ventilator dropped from 88 in 2019, to 50 in 2020 while it is almost the same for mask. The coefficient of reciprocity, which shows the rate at which node pairs are connected by mutual connections, also shows a decrease by about half for ventilator while a small increase is observed for the mask.

According to the distribution graphs in Fig. 1, the strength of the nodes in the networks for both goods increases as a whole in both years, while what is called the average nearest neighbor strength (ANNS) decreases. This distribution indicates the tendency of strong nodes to create links with nodes that are not as strong as themselves, which implies a level of disassortativity. The negative coefficient in Table 1 also statistically confirms this trend.

As mentioned in the methodology section, disassortativity indicates there is a core–periphery structure. The coefficient in Table 1 above, which was developed by Borgatti and Everett (1999), measures how much the network structure from the actual data resembles an ideal core–periphery network structure. The data

Table 1 Descriptive network statistics. Source: Authors' calculations

Basic statistics	Mask		Ventilator	
	2019	2020	2019	2020
Nodes	208	208	203	203
Edges	6254	7353	3221	2003
Clustering	0.907	0.880	0.875	0.921
Assortativity	−0.037	−0.024	−0.094	−0.086
Transitivity	0.489	0.510	0.385	0.248
Reciprocity	0.491	0.521	0.343	0.168
Density	0.145	0.171	0.079	0.049
Core–Periphery fitness correlation	0.701	0.708	0.707	0.747

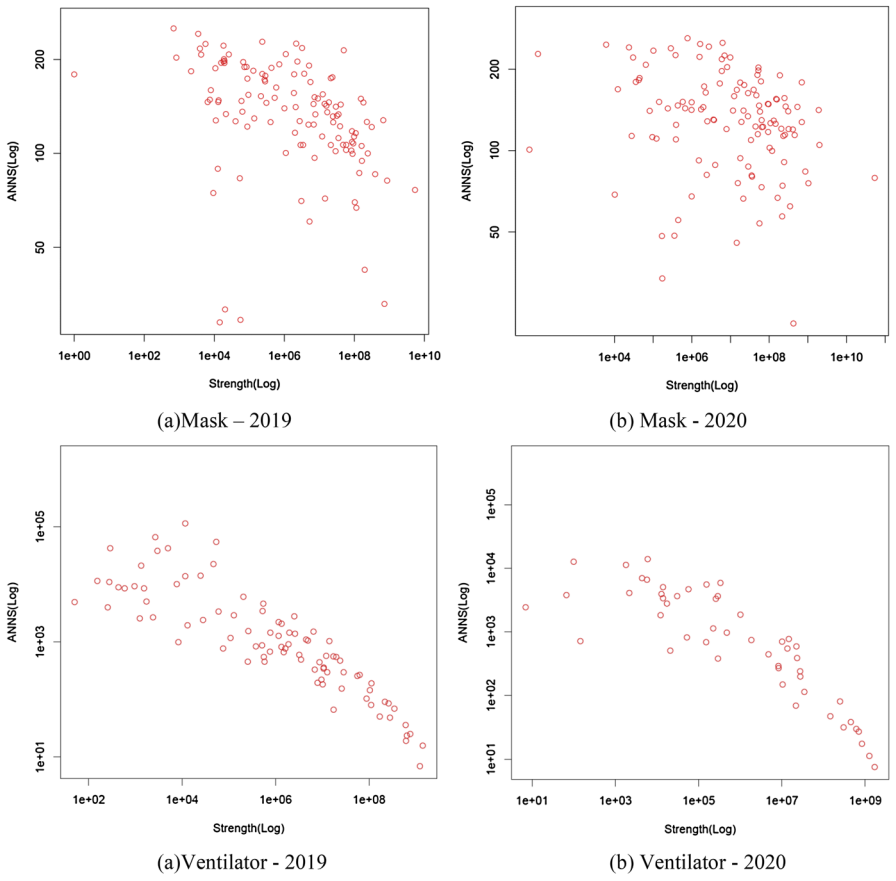
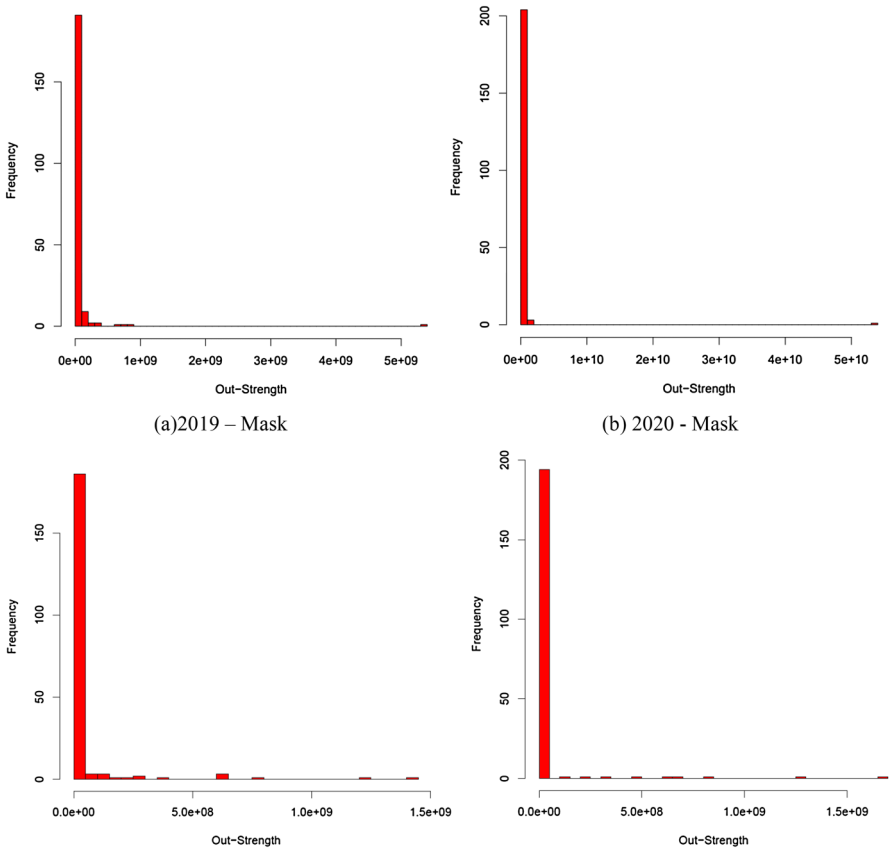


Fig. 1 Assortativity/disassortativity. Source: Authors' draw

shows that the ventilator trade network includes an ideal core–periphery structure at a rate of approximately 71% in 2019, and this rate increased to approximately 75% in 2020. Besides, the mask trade network has an ideal core–periphery structure at a rate of 70% in 2019, and this rate stays almost stable in 2020.

Examining the degree/strength distributions is of particular importance in network analysis. One of the reasons is that many studies which are based on examinations of real-world networks show distribution structures that follow a power-law distribution. As mentioned in the methodology section, when a network has a power-law distribution, it is an indicator of the complexity of the network. This is due to the heterogeneous structure of the connections in the network which is shown by how well it corresponds with the power-law distribution. The distributions displayed in Fig. 2 clearly demonstrate features of a heterogeneous distribution. Specifically, the presence of a small number of nodes with high strength along with a large number of low-strength nodes shows a heterogeneous structure in the network.



(a)2019 – Mask (b) 2020 - Mask

(a)2019 – Ventilator (b) 2020 - Ventilator

Fig. 2 Strength distribution. Source: Authors' draw

It is important to examine these distributional properties statistically as well. The distribution statistics in Table 2 indicate a positive skewness and the kurtosis coefficients show that the distribution is right-skewed and corresponds with a heavy-tail distribution. Moreover, the results of the Kolmogorov–Smirnov test, which tests

Table 2 Fitness to power-law distribution. Source: Authors' calculations

Statistics	Mask		Ventilator	
	2019	2020	2019	2020
Skewness	12.922	14.234	6.096	6.964
Kurtosis	178.114	204.392	43.770	56.178
α	1.552	1.970	1.338	3.279
p value	0.228	0.063	0.226	0.982
KS statistics	0.154	0.999	0.151	0.208

the level of correspondence with the power-law distribution, were also obtained. The findings indicate that the null hypothesis, which expresses its level of congruence with a power-law distribution when the p-value is greater than 0.05, cannot be rejected for both networks. Therefore, the analysis demonstrates statistically that for both years the mask and ventilator trade networks follow the power-law distribution. It is also seen that α value increases for both networks from 2019 to 2020, meaning that the number of super nodes decrease from 2019 to 2020 as well.

Considering the heterogeneity of the links in the network and the core–periphery features of the network together, it is important to identify the cores or main hubs in the network. For this purpose, the hub and authority centrality analysis developed by Kleinberg (1999) is applied. There are many advantages of this method especially for analysing trade networks, as the method calculates a hub and an authority centrality value for each node in the network. The values for the hub centrality correspond to the impact on exports, and the values for authority centrality correspond to the impact on imports for each country. Calculated based on the idea that there is a mutually reinforcing relationship between the nodes, these values give a more in-depth assessment compared to first-degree indicators such as the shares of a country's imports and exports. For example, if a good hub is in a trade relationship with good authority, this relationship further increases the systemic importance of the hub in the network, and the centrality values of that hub reflect its level of systemic importance. Similarly, an authority is a better authority if it has a trade relationship with a good hub. In other words, the fragility of an authority in this network can increase in proportion to the existence of certain trade links. Fragility refers to suffering from shortages of the traded goods within the trade structure. To compare first-degree indicators and high-degree indicators, the shares of exports and imports for each country as well as the hub and authority centralities are displayed below.

Table 3 includes the top 15 countries in both years according to both hub centrality figures and the share of exports. We should first mention that export shares decrease from 2019 to 2020, except in China. China's share of total export of mask increases from 47% in 2019 to 78% in 2020. This pioneering role of China for both years is also observed in hub centrality measures. Even if Germany ranks second in terms of share in export, Vietnam is observed as the second most systemically important country within this network. Canada, USA, United Kingdom and France are the western countries in which systemic importance decreased from 2019 to 2020.

In Table 4, USA is the country ranking first in terms of both indicators. An increase is observed in import shares of Germany, Japan, United Kingdom, France, Italy and Canada. The European countries among these mentioned countries faced high death rates at the beginning of the pandemic. It is possible to observe the fragility of these countries in centrality measures. Germany becomes the second most fragile economy following the US. Italy, as one of the most affected European countries, ranked 14th in 2019 and upsurges 6th in 2020.

Table 5 includes the top 15 countries in both years according to both hub centrality figures and the share of exports. In this table, we can evaluate each year itself as well as make a comparative analysis of the two years. In 2019, Singapore ranks first in terms of both hub centrality and export share. Interestingly, there

Table 3 Hub scores and export shares for mask. Source: Authors' calculations

2019				2020			
Country rankings	Hub centrality	Country rankings	Export share	Country rankings	Hub centrality	Country rankings	Export share
CHN	0.984	CHN	47.049	CHN	0.998	CHN	78.430
VNM	0.156	DEU	7.524	VNM	0.053	DEU	2.917
CAN	0.062	USA	6.309	HKG	0.014	VNM	2.793
IND	0.029	VNM	5.833	DEU	0.010	USA	1.512
DEU	0.023	IND	3.429	CAN	0.009	HKG	1.258
DOM	0.020	NLD	2.739	KOR	0.008	NLD	1.021
HKG	0.019	FRA	2.111	LKA	0.007	KOR	1.020
NLD	0.014	POL	1.988	NLD	0.006	TUR	0.787
USA	0.014	MAR	1.723	TUR	0.005	FRA	0.668
THA	0.012	GBR	1.585	THA	0.004	GBR	0.620
TUR	0.009	CAN	1.431	USA	0.004	POL	0.598
GBR	0.009	HKG	1.406	AUT	0.004	AUT	0.508
FRA	0.008	ROU	1.344	IND	0.003	BEL	0.465
PAK	0.007	TUR	1.207	GBR	0.003	IND	0.455
POL	0.007	JPN	0.994	POL	0.003	CZE	0.390

Table 4 Authority scores and import shares for mask. Source: Authors' calculations

2019				2020			
Country rankings	Authority centrality	Country rankings	Import share	Country rankings	Authority centrality	Country rankings	Import share
USA	0.939	USA	26.199	USA	0.843	USA	25.025
JPN	0.240	DEU	7.619	DEU	0.261	DEU	9.094
DEU	0.117	JPN	6.707	JPN	0.239	FRA	7.790
GBR	0.114	FRA	4.466	GBR	0.231	JPN	6.831
NLD	0.080	GBR	4.124	FRA	0.218	GBR	6.731
KOR	0.070	ESP	3.905	ITA	0.143	ITA	4.362
CAN	0.065	NLD	3.122	CAN	0.101	CAN	3.319
AUS	0.062	CAN	3.089	ESP	0.082	ESP	2.971
FRA	0.051	MEX	3.002	NLD	0.080	NLD	2.784
HKG	0.048	POL	2.213	AUS	0.049	BEL	1.643
VNM	0.039	ITA	2.141	RUS	0.044	AUS	1.486
MYS	0.033	KOR	1.959	BEL	0.044	SGP	1.389
ESP	0.032	AUS	1.947	KOR	0.043	MEX	1.336
ITA	0.029	BEL	1.915	SGP	0.042	KOR	1.255
POL	0.027	CHN	1.513	MEX	0.031	RUS	1.240

Table 5 Hub scores and export shares for ventilator. Source: Authors' calculations

2019				2020			
Country rankings	Hub centrality	Country rankings	Export shares	Country rankings	Hub centrality	Country rankings	Export shares
SGP	0.934	SGP	19.134	USA	0.674	USA	26.042
AUS	0.236	USA	16.674	NZL	0.379	DEU	19.457
CHN	0.206	CHN	10.310	DEU	0.360	NLD	12.878
IRL	0.095	DEU	8.746	IRL	0.335	NZL	10.832
NZL	0.091	NLD	8.385	NLD	0.319	IRL	9.423
DEU	0.059	AUS	8.259	CHE	0.177	CHE	6.970
CAN	0.050	NZL	4.751	GBR	0.110	GBR	4.688
CHE	0.046	GBR	3.801	CAN	0.091	HKG	3.867
SWE	0.032	IRL	3.543	HKG	0.076	CAN	2.251
USA	0.030	CHE	2.966	ISR	0.010	ESP	0.536
FRA	0.021	FRA	2.311	JPN	0.007	ISR	0.429
CRI	0.020	CZE	1.527	ESP	0.005	DNK	0.424
GBR	0.020	CAN	1.511	HUN	0.004	HUN	0.357
NLD	0.015	SWE	1.412	LTU	0.004	LTU	0.344
MYS	0.012	ITA	1.207	DNK	0.003	JPN	0.337

is little difference between Singapore and the US with respect to their share in exports, however, there is a significant difference between Singapore and Australia, which turns out to rank second in terms of hub centrality. This indicates that Singapore has strong trade relations with major importing countries in the network. In addition, the US, which has the second-highest level with respect to its share of exports, ranks 10th with a relatively low hub centrality value. This suggests that the US does not export to major importing countries in the network in the same proportion, so although its share of exports is high, its systemic importance in the network at this level is not high. On the other hand, Australia, whose hub centrality value follows right behind Singapore, is ranked 6th in its share of exports. This shows that although Australia's share of exports is not very high, it is a country of high systemic importance that supplies products to major importing countries in the network. A final observation for 2019 shows that China is also an important hub for international trade in ventilators as it ranks 3rd for both these indicators.

Naturally, in 2020, there are significant changes in the centrality structure of the network in terms of both export rankings and centrality values. First of all, it should be noted that Singapore, which ranked first with a very significant hub centrality ranking in 2019, is not even among the top 15 countries in 2020. Knowing that this trade structure formed as a GVC because of its level of specialisation, it was not expected to show such a dramatic shift in a short time under normal conditions. It is clear that these results reflect the effects of the pandemic. Another important finding is the convergence observed in the centrality values. While there is only one exporter that can be characterised as a super-hub in 2019, there are multiple exporting countries with high hub centrality values in 2020. This shift can be observed from the network visualisations in the Appendices. Appendices 1 and 2 visualise the trade relations among the countries in terms of export. The size of the nodes represents the hub centralities. Accordingly, observation of Appendices 1 and 2 highlights how many countries were forced to quickly adapt to the onset of the pandemic.

The results in Table 6, where the authority centrality values and the shares of imports are compared, show that the US ranks first with a significant difference for both indicators in 2019. The Netherlands follows the US in both indicators as well. While China ranks 7th in terms of the share of imports, it ranks 3rd in terms of its authority centrality values. This indicates that China has trade connections with major exporters and the level of fragility has increased for this reason. In 2020, the US again ranks first in terms of both indicators. However, the significant gap between the countries behind the US for both values has considerably narrowed compared to 2019. In other words, in 2020, the authority centrality values increased for most countries in general and overall, the values have converged toward each other as shown on the network visualisations in Appendices 3 and 4. Furthermore, in the import centrality rankings, the fact that countries that closely follow the US are highly developed countries suggests that the structures of global trade could also contain some moral concerns. Naturally, the supply of products that are vital for the treatment of Covid-19 patients in a global pandemic is essential for every country regardless of geography.

Table 6 Authority scores and import shares for ventilator. Source: Authors' calculations

2019				2020			
Country rankings	Authority centrality	Country rankings	Import shares	Country rankings	Authority centrality	Country rankings	Import shares
USA	0.958	USA	27.393	USA	0.402	USA	11.066
NLD	0.279	NLD	9.816	DEU	0.371	DEU	7.086
CHN	0.037	DEU	6.569	CAN	0.335	FRA	6.670
AUS	0.029	FRA	5.067	FRA	0.311	GBR	5.768
JPN	0.026	JPN	4.988	GBR	0.305	NLD	5.089
DEU	0.020	GBR	3.932	JPN	0.279	CHN	4.829
SGP	0.015	CHN	3.890	NLD	0.279	CAN	4.474
IND	0.013	CAN	2.993	CHN	0.274	JPN	4.111
GBR	0.013	ITA	2.374	MEX	0.199	RUS	3.401
IDN	0.012	ESP	2.051	ITA	0.123	ITA	2.955
FRA	0.011	SGP	2.004	RUS	0.116	MEX	2.769
KOR	0.008	IND	1.802	IND	0.104	ESP	2.307
CAN	0.007	AUS	1.701	AUS	0.104	IND	2.016
BRA	0.007	BRA	1.394	SGP	0.102	AUS	1.957
HKG	0.007	RUS	1.367	ESP	0.096	SGP	1.957

5.2 Empirical results for Turkey

When Turkey's centrality scores within the global ventilator trade network are evaluated, it is seen that the importer identity of the country is more prominent in both years analysed. While Turkey ranked 33rd in the hub centrality ranking in 2019, it ranked 23rd in the authority centrality ranking with a higher score. In 2020, Turkey ranked 73rd in terms of hub centrality, which represents the exporter impact while it ranked 31st according to the authority centrality, which represents the import impact. However, the authority centrality score is higher in 2020 than in 2019, meaning that Turkey becomes more fragile in this global trade network of ventilators from 2019 to 2020.

When it comes to masking, Turkey's export share decreased from 1.2% in 2019 to approximately 0.8% in 2020. Even if there is an increase in ranking, Turkey's hub centrality also decreases. A decrease also observed in import share from 0.3% in 2019 to 0.07% in 2020. The same kind of decrease is also observed in terms of authority centrality. In the beginning of the pandemic, there was a shortage of face masks in Turkey. However, this shortage issue was solved by starting mask production in textile mills, factories, etc.

Evaluating all of these results from masks and ventilators for Turkey, we can say that it is probable to correspond to urgent conditions when it comes to low-tech goods. Although Turkey has not experienced a critical shortage of medical ventilators as much as European countries since the beginning of the pandemic, a comparison of the situations before and after the pandemic highlights the importance of the country's importer identity within this trade network.

6 Conclusion

With globalisation, especially in the post-1980 period, liberalisation policies were implemented under the guidance of the Washington Consensus and global value chains began to shape the structure of the system of international trade. This process became more entrenched at an institutional level with the establishment of the WTO and it resulted in the concentration of global production in certain geographical areas. The system came together with the aim of increasing the profitability of capital on a global scale. While the separation and specialisation of production and consumption on a global level were not particularly alarming during what might be called the "normal" period before the Covid-19 pandemic, the system has now been significantly criticised as a result of the experiences during the Covid-19 era. Access to essential medical products, whose demand has increased in the wake of the pandemic, has been severely restricted because of the lack of production capacity.

In this context, the present study examines the global trade network for face masks and medical ventilators using complex network analysis. The findings indicate that the trade network of these goods is under the control of a small number of super hubs, which increases the vulnerability of the network. Within this scope, the findings support the views stated by Baltzan (2020). Even if the trade relations in mask network seem to be less affected since most countries

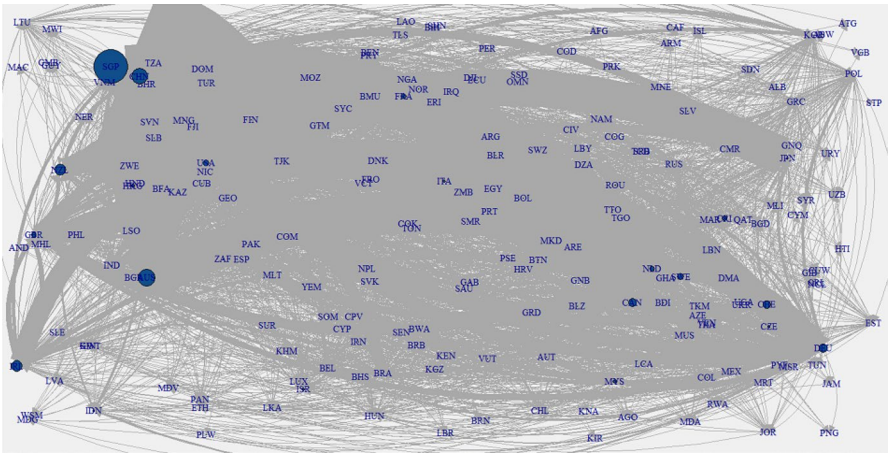
have the ability to adjust their production due to masks' basic/unsophisticated inherent, we cannot observe the same for ventilators. This highlights the question of how countries should address this political economy issue in the post-pandemic period.

Globalisation and the resulting concentration of the profit-oriented production system provide a low level of immunity against emergencies such as a pandemic. As a result, the issue has begun to be more critically evaluated under a broader scope by looking at the function of the market and the role of the state. Laissez faire system has started to be criticised within this scope. In terms of economic demand, the moral challenges cannot be ignored as well. The fact that developed countries are at the top of the country rankings in terms of ventilator imports suggests that the market system has not enabled a balanced supply of this vital product for less developed countries.

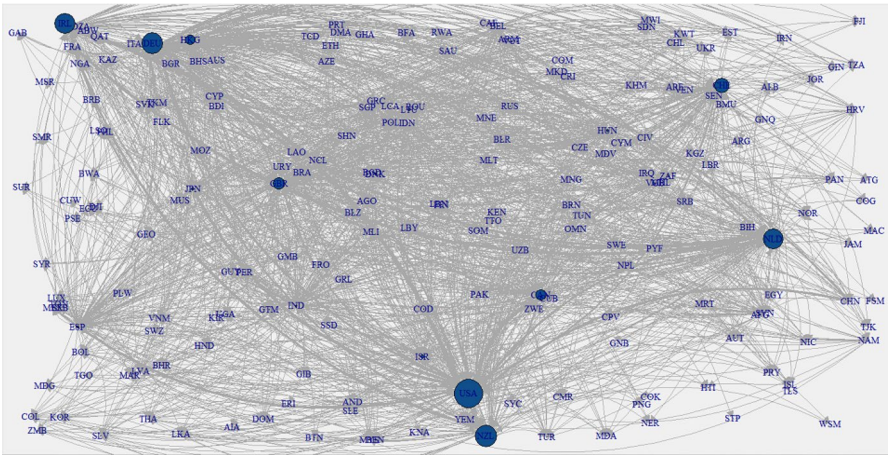
The study fills an important gap in the literature, as there is no empirical study on the global trade of medical ventilators and its consequences. However, the study has some limitations. In addition to this type of topological analysis, it is also possible to measure with a simulation technique how supply shocks might cause fragility within a network. However, since the data required for this is not available, this kind of simulation technique could not be applied. However, the study is open to further development as the availability of data continues to emerge.

Appendices

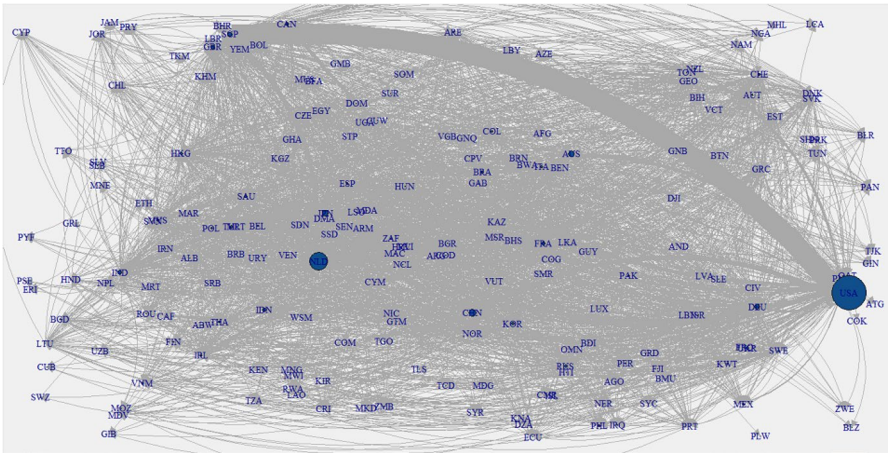
Appendix 1. Network Visualization in terms of hub centralities (2019)



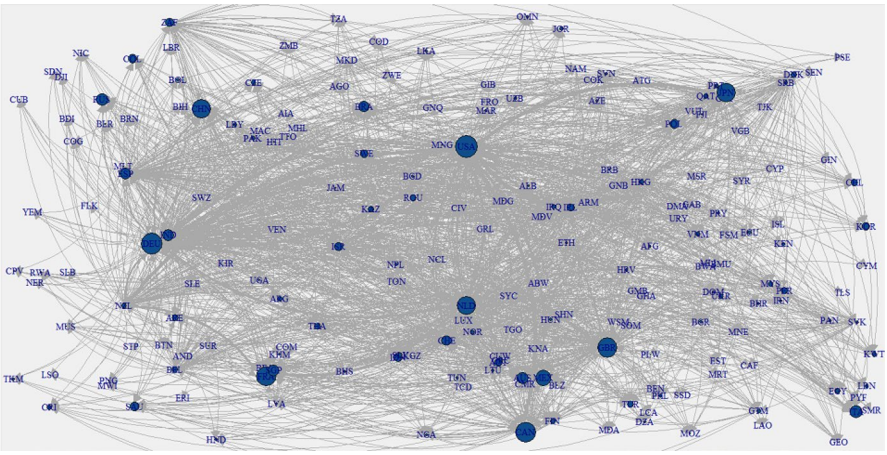
Appendix 2. Network Visualization in terms of hub centralities (2020)



Appendix 3. Network Visualization in terms of Authority centralities (2019)



Appendix 4. Network Visualization in terms of Authority centralities (2020)



Appendix 5. 3-digit Country Codes and Names of the Countries

3-digit country codes	Countries	3-digit country codes	Countries	3-digit country codes	Countries	3-digit country codes	Countries
ABW	Aruba	DJI	Djibouti	KNA	Saint Kitts and Nevis	PYF	French Polynesia
AFG	Afghanistan	DMA	Dominica	KOR	South Korea	QAT	Qatar
AGO	Angola	DNK	Denmark	KWT	Kuwait	ROU	Romania
AIA	Anguilla	DOM	Dominican Republic	LAO	Laos	RUS	Russian Federation
ALB	Albania	DZA	Algeria	LBN	Lebanon	RWA	Rwanda
AND	Andorra	ECU	Ecuador	LBR	Liberia	SAU	Saudi Arabia
ARE	United Arab Emirates	EGY	Egypt	LBY	Libya	SDN	Sudan
ARG	Argentina	ERI	Eritrea	LCA	Saint Lucia	SEN	Senegal
ARM	Armenia	ESP	Spain	LKA	Sri Lanka	SGP	Singapore
ATG	Antigua Barboda	EST	Estonia	LSO	Lesotho	SHN	Saint Helena
AUS	Australia	ETH	Ethiopia	LTU	Lithuania	SLB	Solomon Islands
AUT	Austria	FIN	Finland	LUX	Luxembourg	SLE	Sierra Leone

3-digit country codes	Countries	3-digit country codes	Countries	3-digit country codes	Countries	3-digit country codes	Countries
AZE	Azerbaijan	FJI	Fiji	LVA	Latvia	SLV	Slovenia
BDI	Burundi	FLK	Falkland Islands	MAC	Macao, China	SMR	San Marino
BEL	Belgium	FRA	France	MAR	Morocco	SOM	Somalia
BEN	Benin	FRO	Faroe Islands	MDA	Moldova	SRB	Serbia
BES	Bonaire	FSM	Micronesia	MDG	Madagascar	SSD	South Sudan
BFA	Burkina Faso	GAB	Gabon	MDV	Maldives	STP	Sao Tome and Principe
BGD	Bangladesh	GBR	Great Britain	MEX	Mexico	SUR	Suriname
BGR	Bulgaria	GEO	Georgia	MHL	Marshall Islands	SVK	Slovakia
BHR	Bahrain	GHA	Ghana	MKD	North Macedonia	SVN	Slovenia
BHS	Bahamas	GIB	Gibraltar	MLI	Mali	SWE	Sweden
BIH	Bosnia and Herzegovina	GIN	Guinea	MLT	Malta	SWZ	Eswatini
BLR	Belarus	GMB	Gambia	MNE	Montenegro	SYC	Seychelles
BLZ	Belize	GNB	Guinea-Bissau	MNG	Mongolia	SYR	Syria
BMU	Bermuda	GNQ	Equatorial Guinea	MOZ	Mozambique	TCD	Chad
BOL	Bolivia	GRC	Greece	MRT	Mauritania	TGO	Togo
BRA	Brazil	GRD	Grenada	MSR	Montserrat	THA	Thailand
BRB	Barbados	GRL	Greenland	MUS	Mauritius	TJK	Tajikistan
BRN	Brunei Darussalam	GTM	Guatemala	MWI	Malawi	TKM	Turkmenistan
BTN	Bhutan	GUY	Guyana	MYS	Malaysia	TLS	Timor Leste
BWA	Botswana	HKG	Hong Kong	NAM	Namibia	TON	Tonga
CAF	Central African Republic	HND	Honduras	NCL	New Caledonia	TTO	Trinidad and Tobago
CAN	Canada	HRV	Croatia	NER	Niger	TUN	Tunisia
CHE	Switzerland	HTI	Haiti	NGA	Nigeria	TUR	Turkey
CHL	Chile	HUN	Hungary	NIC	Nicaragua	TUV	Tuvalu
CHN	China	IDN	Indonesia	NLD	Netherlands	TZA	Tanzania
CIV	Côte d'Ivoire	IND	India	NOR	Norway	UGA	Uganda

3-digit country codes	Countries	3-digit country codes	Countries	3-digit country codes	Countries	3-digit country codes	Countries
CMR	Cameroon	IRL	Ireland	NPL	Nepal	UKR	Ukraine
COD	Democratic Republic of the Congo	IRN	Iran	NZL	New Zea-land	URY	Uruguay
COG	Congo	IRQ	Iraq	OMN	Oman	USA	United States
COK	Cook Islands	ISL	Iceland	PAK	Pakistan	UZB	Uzbekistan
COL	Colombia	ISR	Israel	PAN	Panama	VCT	St. Vincent and the Grenadines
COM	Comoros	ITA	Italy	PER	Peru	VEN	Venezuela
CPV	Cabo Verde	JAM	Jamaica	PHL	Philippines	VGB	Virgin Islands (British)
CRI	Costa Rica	JOR	Jordan	PLW	Palau	VNM	Vietnam
CUB	Cuba	JPN	Japan	PNG	Papua New Guinea	VUT	Vanuatu
CUW	Curacao	KAZ	Kazakhstan	POL	Poland	WSM	Samoa
CYM	Cayman Islands	KEN	Kenya	PRK	North Korea	YEM	Yemen
CYP	Cyprus	KGZ	Kyrgyzstan	PRT	Portugal	ZAF	South Africa
CZE	Czechia	KHM	Cambodia	PRY	Paraguay	ZMB	Zambia
DEU	Germany	KIR	Kiribati	PSE	State of Palestine	ZWE	Zimbabwe

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