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RESEARCH PAPER

Modeling the Commercial Flow of Primary Agricultural Products between Iran and the Eurasian Economic Union Member Countries Using a Network Approach[1]

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Abstract
Trade and supply of primary agricultural products are crucial and strategic. Therefore, analyzing the trade network and understanding the country's position in the trade flow of primary agricultural products is paramount. This study used a network model to examine Iran's position in the trade flow of primary agricultural products with EAEU member countries between 2000 and 2021. The network's characteristics and Iran's network indices were calculated. According to the results, all the networks formed in these years had high power distribution and clustering coefficients. Also, the betweenness centrality index results show that Iran was not an influential country in the EAEU primary agricultural products trade network during the study years. Iran must benefit more from this union's primary agricultural product trade capacities and take operational measures to increase its role in the trade network of basic agricultural products with the Eurasian Economic Union.
Keywords: betweenness centrality, complex networks, eigenvector centrality, food security, trade networks.
JEL Classification: F14, F19.

Introduction

Trade and food security are two vital and related aspects of human societies. As one of the basic principles of country development, food security is goal communities worldwide seek to achieve. Ensuring adequate food and nutrition for everyone under normal conditions and against various shocks is critical. One of the most significant ways to ensure food security in the modern economic world is to use other countries' facilities and capacities. This can be achieved through trade.

[1]. This article is extracted from a doctoral thesis.

Trade has positive and negative effects on food security. On the positive side, trade can help balance regional differences in climate and biodiversity and expand consumer choice by balancing food deficits and surpluses on domestic markets (Bilali and Vesna, 2021; Berkum, 2021). In addition, trade can expose small producers to heightened competition and speed up the "food transition." Therefore, trade liberalization is necessary to ensure that trade contributes substantially to food security. Through trade, low-income countries with food insecurity can strengthen their food and agriculture sectors' competitiveness and enhance national food security. There is ample historical evidence that international trade promotes economic growth by allowing countries to use their resources more effectively by specializing in the products and services in which they have a comparative advantage (Brooks and Matthews, 2015; Martin and Laborde, 2018). Therefore, considering the importance of trade in ensuring food security, the positive relationship between international trade and all four dimensions of food security is described below:

• Trade contributes to food availability by enabling imports to cover shortfalls in domestic supply, thus significantly meeting food demand in food-deficient countries.

• Trade increases access to food by accelerating economic growth, increasing income and purchasing power, and lowering consumer prices.

• Trade improves food use because of increased overall demand for food (due to economic growth and higher incomes) and because more income can be devoted to purchasing nutrient-dense food. In addition, trade may contribute to a more varied diet by providing a variety of food products not otherwise available locally.

• Trade increases food stability by balancing food surpluses and deficits. It also reduces seasonal effects on local food availability and makes local markets less susceptible to policy or climate shocks.

Trade effects on different dimensions of food security can be positive, negative, or neutral. They can also be different for each segment of society (e.g., food producer, consumer, trader, and non-agricultural activities) (Figure 1).

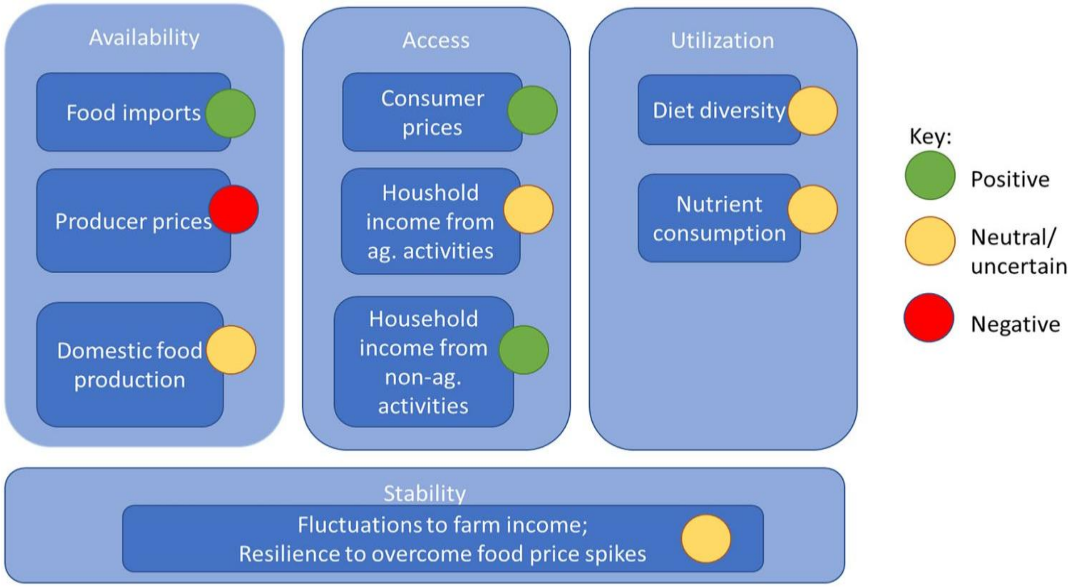

Figure 1. How International Trade Affects Food Security in Food-Deficient Countries' Four Dimensions
Source: Berkum (2021).

A significant point in international trade studies in recent years is examining the trade network and the position of countries in this network. In the last decade, many applied studies in socio-economic systems have been carried out through network analysis. A network is a mathematical description of the state of a system at a point in time through connections and nodes (edges and vertices). The idea that socio-economic systems can be analyzed like networks has a relatively long history (Wasserman and Faust, 1994). Therefore, the use of the network model in the field of trade among economists is expanding day by day. In this context, the network approach has also been used in the applied works of world trade (for example, Serrano and Begona, 2003; Castel and Stein, 2005). In these studies, trade relations are considered as a network in which countries are the nodes and trade relations between countries are the edges between these nodes.

This study investigates the general characteristics of the trade network of primary agricultural products[1] over time between Iran and the Eurasian Economic Union[2]. It identifies Iran's position in this network using the indicators introduced

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[1]. The primary commodities considered in this article include wheat, barley, rice, corn, soybeans and oilseeds.
[2]. The Eurasian Economic Union is an economic and political union of five countries in Eurasia. It was created to promote economic integration and cooperation among its member states. This union

in this field, which have been investigated previously in this context. Therefore, considering the importance of trade in providing sustainable food security and its impact on food security indicators, as well as the role of trade networks in international trade studies, in this research, the trade flow network between Iran and the Eurasian Economic Union in primary agricultural products, as one of the country's leading trade partners, is examined in recent years. First, the agricultural trade network and its impact on food security will be explored. In the next section, the studies are reviewed, and the research model is presented. Then, the results will be discussed, and conclusions and recommendations will be offered.

Agricultural Trade Network and Food Security

With globalization and economic integration deepening, economic relations between countries are increasingly strengthened and gradually form mutual dependence, competition, influence, and mutual restrictions (Lambin and Meyfroidt, 2011; Griffin, 2003). In this regard, more countries have sought to gain more from the global trade of agricultural products and, in this way, compensate for their supply gap and create an international channel for transferring agricultural surpluses and shortages (Anderson, 2010; MacDonald et al., 2015). Therefore, agricultural trade is essential in promoting the new wave of economic growth and transregional allocation of water resources and arable land (Liu et al., 2013; MacDonald et al., 2018). Between 1961 and 1970, world trade in agricultural products increased by 18.6 billion, while from 2009 to 2018, this figure accelerated significantly to 487.8 billion (World Bank, 2021). As the diet structure of developing countries changes, the gap between global supply and demand for agricultural products is expected to increase continuously, and trade in agricultural products will also become more prosperous (FAO, 2021; Porkka et al., 2013). Therefore, analyzing global food security from an agricultural trade perspective is critical to discussing sustainable development worldwide.

Further trade network studies of various food types have emerged as research continues. These include those focusing on seafood (Gephart, 2015), meat (Chung et al., 2020; Li et al., 2021), cereal (Duan et al., 2022), and soybean (Sun, 2018). Research into the growing segmentation of trade networks involving wheat (Fair

is designed to create a common market and facilitate the free movement of goods, services, capital and labor. It is also expected to increase economic competition in the region. The member countries are Russia, Belarus, Kazakhstan, Armenia and Kyrgyzstan. Russia initiated the Eurasian Economic Union. It officially appeared on January 1, 2015, after the signing of the Eurasian Economic Union Treaty in 2014 (Eurasian Economic Union website, 2023).

et al., 2017; Gutiérrez-Moya et al., 2021), maize (Wu and Guclu, 2013) and rice (Zhou and Wang, 2020) provide necessary theoretical support for developing more beneficial, evidence-based food security strategies. In terms of research methods, many studies have used quantitative measures of network characteristics, such as node strength, network density, betweenness centrality (Nie et al., 2022; Torreggiani et al., 2018; Dong et al., 2018), community detection (Wang and Dai, 2021; Blondelvd, 2008), and core-periphery structure (Chen and Li, 2019; Han et al., 2021).

Recently, the Agricultural Trade Network (ATN) has been severely challenged by the escalation of trade tensions and the global outbreak of the pandemic. On the one hand, major exporting countries, led by the United States, have tightened export controls on some major importing countries. On the other hand, other vital exporters, such as Russia and Ukraine, have been affected by the pandemic and their national relations, which prevents them from participating in international markets (Behanasi and Haiba, 2022). Along with the rapid growth of the Global South, trade unilateralism and protectionism have emerged, and increasing trade tensions and intensifying conflicts have significantly increased potential risks for ATN (Adamchick and Perez, 2020). Since 2020, critical international wheat exporters—Kazakhstan and Russia—and Vietnam, the leading rice exporter, have implemented export bans, which have shaken the international trade market. From a global perspective, ATN stability helps ensure efficient and robust performance throughout the agricultural system. However, the US-China and Russia-Ukraine conflicts have a local impact on food security and create a significant global shock. Agricultural trade is critical for countries with insufficient domestic resources to meet domestic needs, especially for populous and fast-growing economies such as China (Shutters, 2012). Trade networks are essential for regional and global food security, economic prosperity, and sustainable development (D'Amour and Anderson, 2020). Getting enough food is economically beneficial not only for exporting countries but also for importing countries. The entire trade network is expected to be at risk if the current dynamic and unstable trade pattern intensifies. This is especially true with the collapse of relations between core countries. Therefore, addressing the potential risks and a deeper but more stable integration into the global agricultural economy has become an urgent issue that must be addressed. This is to end hunger and achieve sustainable food development.

Complex network analysis has become an effective way to understand trade characteristics. The general idea is to construct relevant networks by considering the countries involved in trade as nodes and the connecting lines between two nodes as edges (Garlaschelli and Loffredo, 2009). Some studies have created trade networks to reveal the characteristics and evolution of the oil trade (Zhang et al., 2014), natural gas (Zheng et al., 2014) and advanced products. With the rapid development of international agricultural products trade, related network studies have also increased (Arita et al., 2022) and focus on issues such as building a global ATN for primary agricultural products and analyzing their evolutionary characteristics (Muthayya et al., 2014). In addition, researchers have also investigated the characteristics of embodied resources in agricultural trade from the perspective of the flow of water resources and arable land (Qiang et al., 2020). It was found that major producing countries, represented by Brazil, are key players in meeting global food demand. They have a significant impact on ATN growth. With the complexity of the international agricultural trade environment, trade stability has emerged as a new research focus. However, existing studies analyze specific targets, such as cereals, fruits, and fishery products, using only qualitative methods. They are also limited to quantitative methods through individual indicators such as geographical concentration. Since agribusiness is affected by many factors, including political risks, economic benefits, geographical distance, national relations, and cultural characteristics, relevant research should be carried out across the network.

One of the trade networks for agricultural products has been formed between Iran and the Eurasian Economic Union, and with Iran's membership in the Eurasian Economic Union, the potential capacities of this union can be used, given the country's great need to import primary agricultural products, especially wheat and animal inputs. Therefore, examining Iran's position in this trade network and recognizing the opportunities available is pertinent. This is to adopt appropriate economic and commercial policies.

This article aims to answer the following questions:

1. What has been the evolution of the trade network for primary agricultural products between Iran and the Eurasian Economic Union and Iran's position in this network?
2. Which countries play the central role in the investigated network, and what is the role of the countries in the network?

Literature Review

Trade and its impact on food security have been investigated in several studies. Below are the studies conducted in the field of agricultural products trade and its impact on food security.

In Wang et al.'s (2023) study entitled Trade for Food Security: The Stability of Global Agricultural Trade Networks, the authors analyzed the change of the global agricultural trade network from 1986 to 2018 and estimated the grouping characteristics and stability of the network. European-African community, the formation of three-pillar communities, and the development of a multipolar community with a more complex structure. Despite the gradual increase in global ATN nodal stability over the decades, certain gaps can still be found in stability across countries. In particular, the European Community achieved a stability of 0.49 and its trade relations were effectively secured. Meanwhile, the stability of the remaining leading societies shows a stable and upward trend, albeit with more significant challenges in trade relations among some of them. Therefore, how to ensure the stability of trade relations and strengthen global ATN to withstand external shocks has become a fundamental question for maintaining global food security.

Ibrahim et al. (2023) entitled Consequences of Food Security on Sustainability: Does Trade Facilitation, Population Growth, and Institutional Quality Build or Undermine the SSA Goal? This study examines the influential role of trade facilitation (TF) in promoting or hindering food security in a panel of 34 sub-Saharan countries for the period 2005-2019. Empirical evidence based on the generalized method of moments estimator of the two-stage dynamic system is used to account for econometric concerns that concern unobserved heterogeneity and potential endogeneity inherent in the variables used. Empirical findings show that the nature of TF methods, which are inefficient, negatively affects food security in SSA. These effects are evident on the availability and access dimensions of food security as well as their composite index. While it is pointed out that this result contradicts the established positive signs on the one hand, but on the other hand it depicts the reality of the economic phenomenon in SSA. On balance, the current TF regime can best be described as anti-food security, as suggested by the prevailing heavy-handed procedures involved in the export and import of staple food items. The functional roles of population growth and institutional quality are empirically enhanced differently. Further, we recommend that in order to rapidly achieve the goals of food sufficiency and sustainable development, governments in the region should adjust the basic methods of the current TF regime.

Yogeeswari et al. (2023) analyzes the impact of imports on food security in 56 low-middle income countries from 2011 to 2016. The estimation results by adopting the generalized method of moments point to the negative effects of imports on food security. Decomposition analysis for each dimension shows that the level of food availability increases with imports. That is why imports are considered part of the measurement of food security. However, the remaining three dimensions are the level of food access, utilization, and stability, versus imports. This could explain why the negative effects of imports outweigh the positive effects on the net. This study shows that including imports in food security can help ensure sustainable food supply and address domestic production shortfalls through a better import regulation system.

Kareem et al. (2022) in their study examine the consequences of non-adherence to trade practices in African food exports, which has contributed to the increased incidence of food insecurity in the continent. The results of this study show that inefficient trade practices and inconsistent food supplies contribute to the continent's poor performance in meeting food demand, both from the import and export angles.

Chen and Zhang (2022) showed that (1) Grain trade between BRI countries has formed well-connected and complex trade networks. Moreover, the "Belt and Road" initiative has significantly promoted grain trade networks among BRI countries. (ii) the backbone structures of grain trade networks along the BRI are geographically adjacent; India, Russia, and Ukraine are the most critical trade partners and the absolute central nodes in trade networks that influence the entire grain trade networks. (3) BRI grain trade networks exhibit significant core-periphery structures, with significant power asymmetries reflecting food supply and demand differences between countries. In general, BRI grain trade networks are developed. A few large countries dominate supply chains in the grain trade network and are fragile, with poor resilience and low-risk resistance. Therefore, governments should continue strengthening regional cooperation, optimizing the grain trade network structure, increasing storage capacity, and building a more robust system. This will ensure food security and prevent risk. All these measures will support food security in "Belt and Road" countries.

In Behnassi and Haiba's (2022) study entitled "Consequences of the Russia-Ukraine War for Global Food Security" using field and library methods, it was stated that recently, the stability of the agricultural trade network (ATN) has been significantly affected due to the intensification of trade friction and global expansion. The pandemic has been challenging. On the one hand, key exporting countries, led by the United States, have strengthened export controls on some major importing countries. On the other hand, other significant exporters, such as Russia and Ukraine, have been affected by the Coronavirus pandemic and their national relations. This hinders their participation in international markets.

In Berkum's (2021) article, How Can Trade Create Inclusive and Sustainable Food System Outcomes in Food-Deficit Low-Income Countries? Using the field and library method, it argues that trade can cause inclusive and sustainable nutritious food production in low-income countries with food shortages. Still, policies and investments in these countries should focus on diversifying production and markets, increasing competitiveness and improving market access for local farmers. The integration of external factors into international trade should be focused. The paper also highlights the challenges and opportunities of international trade in food systems. It also emphasizes the importance of global collective action to address externalities associated with food production, land use and climate change.

Gupta et al. (2019), in a study titled "The Effects of Geopolitical Risks on Trade Flows: Evidence from the Gravity Model," investigated the effects of geopolitical risks on trade flows among 164 developed and developing countries during the period 1985-2013 using the index of geopolitical risks in the framework of the gravity model. They discussed the results of estimations of fixed effects models, Hausman-Taylor (HT) random effects and Poisson pseudo-maximum likelihood show that geopolitical risks harm trade flows.

Cantore and Cheng (2018), in their study entitled "International trade of environmental goods in gravity models," investigated the factors affecting the trade of environmental goods in the form of a multi-regional data table and gravity model. The results show that strictness in implementing environmental laws is critical in exchanging environmental goods. There is a substitution effect between the two. In addition, innovation, cultural cues, geographical proximity, and uncertainty in financial markets also affect environmental products trade.

Wang et al. (2018) studied 57 agricultural products from the six categories of cereal, oilseeds, fiber, sugar, fruits and vegetables, and meat. They noted the rising density of global agricultural trade networks and their increasing diversification.

Cai and Song (2016) applied a complex network to analyze agricultural and national trade relationships. They found that agricultural trade facilitates international commerce. Foti, Scott, and Rockmore (2013) investigated the strength and dynamics of the global trade network through a weighted graph. In this study, the extinction model, employed in biology, was applied. Biology uses simulation models to investigate the effect of removing an animal species on the ecosystem. This study used this model to assess the impact of trade relationship termination. It also examined the changes in the intensity of the trade relationship of one country with another country or the effect of its removal on the entire trade network. This research tested the global trade network's strength against sudden shocks and fragility to targeted attacks. This research shows that the worldwide trade network is strong against random shocks and fragile against targeted shocks and attacks. Another significant result of this study is the two-way effect of the increase in commercial connections between countries on the strength of this network. In such a way that this increase in communication, which can be a sign of globalization, up to a threshold level can absorb the effect of small shocks and neutralize them, but in case of severe shocks, this increase in communication will spread the shock to all sectors. The network leads and affects the entire network.

Faustino and Leitao (2010) also in their study titled Portugal's Foreign Direct Investment Flows: Empirical Research to Analyze the Effect of Foreign Direct Investment on Mutual Trade Flows between Portugal and the European Union during the period 1996-2005 with fixed effects methods and GMM paid. Their study showed that foreign direct investment (FDI) and the shared border positively affect mutual trade between Portugal and the EU. Other results of this study indicated that market size, economic stability and distance are among the factors affecting mutual exchange between the studied countries.

In a study, Fagiolo et al. (2008) investigated the topology and dynamics of the global trade network using a weighted graph. In this study, 159 countries were considered between 1981 and 2001. The weight given to each edge of this network was supposed to be the arithmetic average of the total exports and imports of the countries to each other. This research calculated the degree of each vertex, i.e., the number of edges (trade relations) that enter each vertex (country). Then, using this concept and taking into account the weight of the global trade network, the idea of "strength of each vertex" was introduced, which is the sum of the weights of each vertex. This index provides information about the trade relations intensity between countries. The examination of the degree index of each vertex shows that if the global trade network is considered an unweighted graph, this index has a very high value. Each country has trade relations with 90 countries on average.

However, if the same index is considered for the weighted network of world trade (the strength index of each vertex is equal to 0.3), the difference indicates that most countries in this network have weak trade relations. Also, both indices have constant time digits. The global trade network has mostly stayed the same despite all the efforts and measures for globalization. Another result of this study is the pattern of worldwide trade network disassortativity. This means countries with many trade relations have more relations with countries with few trade partners. Also, according to this research, there is a positive correlation between the strength of the degree of each vertex and the clustering coefficient. This means stronger countries are more likely to form strong trade clubs.

Using the fixed effects method, Badinger and Breuss (2008) examined the mutual trade flows of 14 OECD member countries for 15 manufacturing industries during 1985-1996. This study showed that productivity positively affects exports and trade volume, increasing trade when the trading partner is close. In other words, this study confirmed a negative relationship between bilateral trade and distance.

Elahi et al. (2019), in a study titled Investigating the effects of the trade agreement between Iran and the Eurasian Economic Union on the export sector of industry and agriculture, an approach to the gravity model examines the impact of the trade agreement between Iran and the Eurasian Economic Union on the export sectors of industry and agriculture using the gravity model between 2001 and 2018. The results show that average gross domestic product and foreign direct investment positively affect Iran's industrial and agricultural exports to Eurasian countries. In contrast, the country's total population, tariff rate, and real exchange rate harm Iran's exports to Eurasia.

Yazdani et al. (2017) concluded that intra-industry trade can increase commercial integration between business partners by expanding goods circulation, reducing the technological gap, and creating economic scale. This study determined the investigated products' trade determinants using the gravity model and Poisson maximum likelihood method during 2015-2016. Then, the trade efficiency of these products was calculated according to the Malmquist index. In the following, the effect of business integration in the form of intra-industry trade indicators on business efficiency during 2017-2018 has been evaluated using the panel data method. Based on the results, the effect of the variables of Iran's GDP per capita and trade partners, the difference in natural gas reserves, the common border and intra-industry trade indicators as representatives of trade integration on the trade of the investigated products is positive and notable. On the other hand, the variable coefficient of geographical distance is negative and significant in the trade pattern of the examined products. Also, the results show that the relationship between trade indicators within the industry and trade efficiency is positive and significant.

In a study titled The Experimental Test of Linder's Theory in Iran's Foreign Trade Pattern, Yazdanparast et al. (2014) examined Iran's bilateral trade and its trading partners based on the period of 2006-2010. The study results showed that the less the difference in per capita income between countries, the more trade between countries will increase. Other results of the study showed that there is a negative relationship between distance and trade volume.

In their research titled "Evaluation of the Effectiveness of Unilateral and Multilateral Sanctions on the Foreign Trade of Non-oil Products in Iran, Kazeroni et al. (2014) evaluated the effectiveness of unilateral and multilateral sanctions on the foreign trade of Iran's non-oil products with its 73 principal trading partners. Using a gravity model and panel data method, they checked:

$$\text{Log (Trade}_{\text{ij}} = \beta_0 + \beta_1 log(Trade_{ij})_{-1} + \beta_2 \text{log}(GDP_i * GDP_j) + \beta_3 \text{log}(Pop_i * Pop_j) + \beta_4 \text{log}(DIST_{ij}) + \beta_5 (DUMSANC_{US,EU,ALL}) + u_{ijt}$$

In the above relation, trade volume between Iran and trading partners, GDP, population (pop), and DIST are the distance variables between countries. This study includes three virtual variables (DUMSANC) to investigate the effect of sanctions: unilateral sanctions by the United States, multilateral sanctions by Europe and the United States, and multilateral sanctions by the United States, Europe, and the United Nations against Iran. In this study, three separate models have been estimated using each variable. Hofbauer (2003) divides sanction variables into three types: limited, moderate, and severe.

According to the findings, the effect of unilateral US sanctions is insignificant. At 0%, multilateral sanctions from Europe and the United States reduce Iran's trade by 22%, and multilateral sanctions from the United States, Europe, and the United Nations by 24%. Accordingly, to investigate the effect of sanctions on Iran's trade expansion with other countries and to eliminate the impact of sanctions, the above models have been estimated for trade between Iran and non-sanctioned countries. The results show that if the United States imposes sanctions, Iran will reduce the effect of these sanctions by expanding its trade relations with other countries. However, suppose Europe and the United States impose sanctions on the United Nations and Iran. In that case, there is no way to avoid sanctions by increasing Iran's trade with other countries. Iran's trade will decrease by about 5%.

Souri (2013), in the study of the analysis of the factors affecting the commercial convergence of Iran with selected regional blocs (the use of a gravity model) with integrated data and with the approach of dynamic panel models and the application of the generalized moments method, showed that economic size, income per capita and foreign direct investment have had significant effects, and distance has an essential but inverse impact on Iran's trade flow with regional blocs.

Jalali and Soleimani (2005) examined the mutual trade flows between Iran and the ECO member countries in studying Iran's trade integration with the ECO member countries for 2003. This study showed Iran converged more with ECO member countries than EU member countries. This is because of the same economic, social, and religious structures of these countries.

According to previous studies, the literature in this field has a brief history (15 years). In the early years, the topology of the trade network of primary agricultural products using simple or weighted and directed or undirected graphs was mentioned. After that, studies have been conducted to investigate the effect of the network topology. This is in crises and their spread, commodity trade bloc development and formation. In other studies that have a more practical aspect, the main focus is on the strength and fragility of this network. Further, the study explores how crises and shocks propagate in these networks. Despite the ever-increasing expansion of trade network studies in our country and until the moment of writing this text, no internal research has been conducted in the field of trade in primary agricultural products between Iran and the Eurasian Economic Union using the network approach, so by examining Iran's position in this trade network, this gap has not been addressed.

Methodology

This research uses the network approach to investigate the trade flow between Iran and the Eurasian Economic Union. In this research, according to complex network theory, the agricultural trade network between Iran and the Eurasian Economic Union can be represented by the set N = (P, E), where P represents a country involved in agricultural trade and P = {P1, P2, …, P6} (a total of 6 here based on the number of countries trading in the Eurasian Economic Union), E represents the line between two nodes, i.e., the edge of the network. The commercial network of primary agricultural products, including wheat, barley, paddy, corn, and oilseeds, between Iran and the Eurasian Economic Union has been built using Gephi software for the years 2000 and 2021 to achieve the goals of research and modeling of the trade model. It should be noted that the network model had not been used in trade and food security before this study. For this reason, this research can be considered a novel contribution to content development in trade and food security studies.

The simplest type of graph is undirected binary graphs. In this type of graph, the vertices can be connected through the edges, and the edges' direction is irrelevant. If the direction of the edges in the network is essential, a directed network (graph) should be considered. In the trade network between countries, the vertices represent the selected countries and the edges represent the commercial relationship of these countries based on export and import. If export and import are a priority, a directed graph is used. Otherwise, an undirected graph is used. In this study, descriptive statistics including the number of edges, average degree, average weighted degree, graph density, and finally the average clustering coefficient are investigated.

Vertex degree measures the bilateral relationship between two vertices and means the number of trading partners each vertex (country) has (Fagiolo et al., 2008). In directed graphs, the degree is divided into two types: in-degree and out-degree. This study represents the number of trading partners in import and export. Edges can be weighted. Weight means giving points to each edge or its values. The strength of the vertex can provide insight into the intensity of trade relationships between countries (Fagiolo et al., 2008). This means that if the export or import value of the weight of each edge is considered, a vertex (country) with more weight (higher vertex strength) has a better trade relationship with other countries. Countries can thus examine trade intensity.

The degree distribution function can be defined according to the network degree and vertex strength. Suppose the considered network is binary and unweighted. This function expresses the probability of a randomly selected vertex with k edges (Fagiolo et al., 2010). If the network is weighted, the likelihood of obtaining a vertex with a weight equal to α can be obtained. The shape of the distribution function can express distinctive features about a network's structure. For example, undirected networks randomly generated have a standard or bell-shaped degree distribution. In contrast, scale-free networks with a right-skewed degree distribution function (power law) have been observed with a large number of vertices with few edges and a small number with many edges (Albert and Barabasi, 2002).

The clustering coefficient is another index of the network. Using this index, it is possible to find out how a country's business partners are related to each other.

For example, if we assume that Iran (i) has trade relations with k countries, these k countries can eventually have k(k − 1)/2 trade relations with each other and form a group or cluster. Now, if in the real world, the number of trade relations between these countries is e, the clustering coefficient is obtained from Equation (1):

$$C_j = \frac{e}{\binom{k}{2}} = \frac{2e}{k(k-1)} \tag{1}$$

The average clustering coefficient is equal to the average of all the clustering coefficients of the countries and is obtained from Equation 2:

$$\bar{c}=(1/N)\sum_{i=1}^{n} c_1 \tag{2}$$

In complex networks, sometimes it becomes essential that the head, actor, or person is at the center of the network. Centrality means having more connections with others. The center is divided into two types: local and general. Local centrality means a vertex with extensive communication with its neighbors. Centrality refers to a vertex with strategic importance for the entire network. One of the criteria for measuring general centrality is the centrality criterion. If (P(kj) represents the number of the shortest paths that exist between k and j and passes through vertex i, and P(kj) is the sum of the shortest paths that exist between k and j, the general centrality criterion can be calculated from Equation (3) (Jackson, 2008):

$$Ce_i^B(g) = \sum_{k\neq j.i\notin\{k.j\}} \frac{p_i(k_j)/p(k_j)}{(n-1)(n-2)/2} \tag{3}$$

Vertices that obtain higher scores are more central because more shortest paths pass through them than through other vertices. Another index used to check centrality is eigenvector centrality. The main goal of this index is to capture the importance of a country’s neighbors in the trade network. It examines the role of neighbors of countries with trade relations. This means that countries that have a high eigenvector score and are central countries based on this index have trade relations with countries that themselves have trade relations with many other countries (De Benedictis et al., 2013). This index is obtained by using the adjacency matrix and computing its principal eigenvector.

Results

Cereals, as the primary food source for humans, play an essential role in feeding the population and account for the largest share of agricultural trade. Therefore, a narrow definition of food, limited to grains, is adopted in this article. Consequently, "cereals" (HS10) as defined in the International Convention for the Harmonized Commodity Description and Coding System include wheat and maize (HS1001), oilseeds (HS1204), Barley (HS1003); Barley (HS1004); Maize (HS1005); rice (HS1006) and soy (HS1201). Trade flow data are derived from the "grains" data in the UN Comtrade database. Countries are considered network nodes, and trade flows between countries constitute edges. First, a 6 × 6 trade network matrix was constructed based on the EAEU spatial extent. Second, trade flows between countries were matched with network matrices and direct and weighted trade network matrices were erected. Finally, the EAEU Cereals Trade Network for 2000 and 2021 was created. Gephi software was used to extract data results. The results for trade between Iran and the five Eurasian Economic Union countries were examined. In this study, two separate networks for import and export are considered.

Export Network Topology

In this research, the export network has been examined for 2000 and 2021[1]. Table 1 shows these results. As seen in Table 1, the average number of export relations, expressed by each country's average degree, with other countries in the Eurasian Economic Union was equal to 2.833 in 2000. This number increased in 2021 and finally reached 6. This increase means more export destinations for the countries than in the past. This can be a reason for the globalization of trade and the formation of more commercial connections among the countries. The network's density, which examines export relations between countries in another way (it is obtained by dividing the number of existing commercial relations by the maximum bilateral relations that could exist between countries), also shows that in this network, more commercial ties are formed between countries.

The density of the network, which examines export relations between countries in another way (obtained by dividing the number of existing trade relations by the maximum number of bilateral relations that could exist between countries), also shows that the network has become denser over time. This means that relations between countries have increased over time, confirming the result of the average degree index.

Figure 2 shows the export network of grains between Iran and the Eurasian Economic Union in 2000:

[1]. International data on primary agricultural product trade between countries has been updated according to the reviewed sites until 2021. For this reason, this year has been reviewed as the most up-to-date year available.

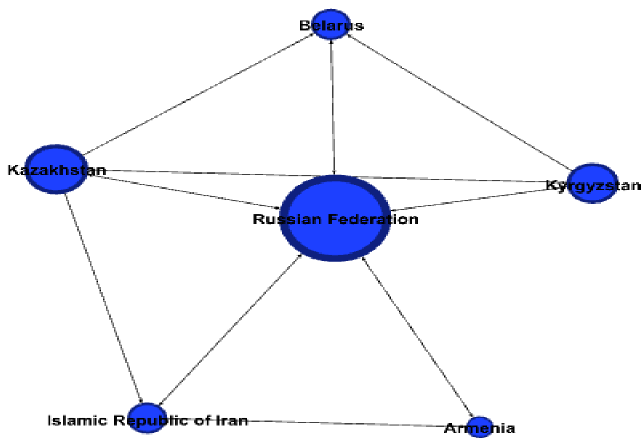

Figure 2. The Export Pattern of Primary Agricultural Products between Iran and the Eurasian Economic Union in 2000
Source: Research finding.

In 2000, the Russian Federation and then Kazakhstan had the most prominent export relations in the export network of primary agricultural products in the Union. The other countries ranked lower.

Figure 3 shows the export network of grains between Iran and the Eurasian Economic Union in 2021:

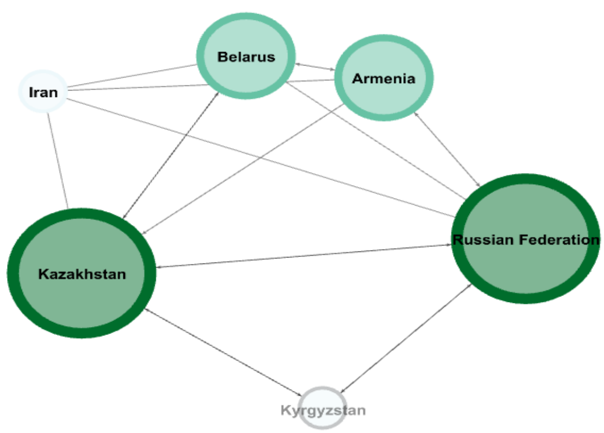

Figure 3. The Export Pattern of Primary Agricultural Products between Iran and the Eurasian Economic Union in 2021
Source: Research finding.

Figure 3 shows the export network of primary agricultural products, including wheat, barley, corn, paddy, soybeans and oilseeds, between Iran and the Eurasian Economic Union. According to the available data and the shape of the network in 2021, trade relations in this area, Russia and Kazakhstan, have played the biggest role in this network. Iran's role in this network was small and it did not play an active role in exporting essential products.

According to Table (1), the average clustering coefficient in this network also states that the countries that are the export destination of certain country's goods have significant trade relations with each other; This point shows that the export network of primary agricultural goods, due to having a high clustering coefficient, can be of the type of complex networks and is intertwined in some way.

Table 1. The Size of the Export Network Indicators between 2000 and 2021

Average clustering coefficient	Graph density	Average weighted degree	Average degree	The number of edges	Year	Matrix type
0.731	0.533	2.667	2.667	17	2000	Export
0.9	0.8	6	6	18	2021	matrix

Source: Research finding.

Import Network Topology

Examining the topology of the import network also indicates that this network is more interconnected. The average degree of this network is higher than that of the export network. It indicates that, on average, countries imported goods from 2.667 countries in 2000, and this figure reached 3.333 in 2021. In this network, commercial connections among the countries have increased.

Figure 4 shows the import network of primary agricultural products between Iran and the Eurasian Economic Union in 2000:

Figure 4. Import Pattern of Primary Agricultural Products between Iran and the Eurasian Economic Union in 2000
Source: Research finding.

Figure 4 shows the import network of primary agricultural products between Iran and the Eurasian Economic Union. According to the available data and the shape of the network in 2000, Russia and Kazakhstan had the most significant import relations in this network and played the greatest role. Iran's role in the import network of primary agricultural products in 2000 was small, and it did not play an active role.

Figure 5 shows the import network of primary agricultural products between Iran and the Eurasian Economic Union in 2021:

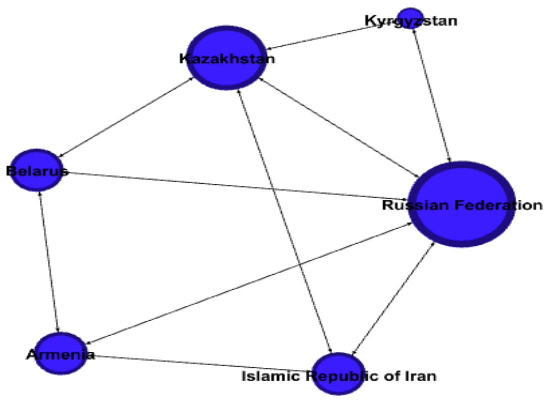

Figure 5. Import pattern of primary agricultural products between Iran and the Eurasian Economic Union in 2021
Source: Research finding.

Figure 5 shows the import network of primary agricultural products between Iran and the Eurasian Economic Union in 2021. According to the available data and the shape of the network in 2021, Russia and Kazakhstan still have the most significant import relations in this network. Iran’s role in the import network of primary agricultural products in 2021 was also limited; it had only two import relations and did not play an active role.

According to the values of the indicators of the import network of primary agricultural products in 2000 and 2021, which is shown in Table 2, the density of this network is also increasing over time, has increased from 0.533 in 2000 to 0.667 in 2021 and it indicates the increase in the number of export relations between countries and confirms the mentioned result.

However, the average clustering coefficient of this network has decreased from 0.731 in 2000 to 0.667 in 2021. This indicates that countries that have trade relations with a particular country trade less with one another than in the past, and import relations among them have weakened.

Table 2. The Size of Primary Agricultural Products Imports Network Indicators in 2000 and 2021

Average clustering coefficient	Graph density	Average weighted degree	Average degree	The number of edges	Year	Matrix type
0.731	0.533	2.667	2.667	16	2000	Import
0.667	0.667	3.333	3.333	20	2021	matrix

Source: Research finding.

Evaluation of Iran's Position in the Trade Network of Primary Agricultural Products in the Eurasian Economic Union

Examining the characteristics of Iran in the export network shows that Iran’s degree centrality was higher than the average degree of the export network in 2000. Still, it was lower in 2021, and compared to other countries, in 2000, it ranked higher only than Armenia. In 2021, its position worsened relative to the other countries, and it shared the same rank as Kyrgyzstan. These results mean that the number of Iran’s trading partners in the export of primary agricultural products in this union was higher than the average of all member countries in 2000. However, they are less in the year 2021. Also, in the import network, Iran’s degree in the import network has been higher than the average degree of the import network in 2000 and 2021, and the number of Iran’s import partners increased in 2021. The country of the Russian Federation has had commercial relations with all the countries in this network. Having multiple commercial relations means access to more diverse markets. On the other hand, Iran has relations with fewer countries in this union in agricultural trade. This point can be important for Iran, which has been affected by economic sanctions because by diversifying the trading partner countries by being a member of this union and using its capacities, the harmful effects on the country's food security of Iran's removal from the global trade network due to sanctions can be reduced.

Examining the centrality index shows that only the Russian Federation has a higher betweenness centrality score than Iran. This can be likened to a hub airport that transfers flights to other destinations. This is one of the most prominent features of countries with a favorable trade position. This feature is also clearly seen in the goods import network. Countries such as the Russian Federation and Kazakhstan in 2021 have the highest betweenness centrality scores. For this reason, removing these countries from the trade network can affect the entire network and other countries. Other countries will also be affected if a crisis occurs in these countries.

Business partners can influence that country's business. It may be possible to examine the relations of business partners of a country with other countries from an economic and political perspective. These interests pertain to a country connected to a few others. Based on this, Iran's position compared to the selected countries regarding the importance of trading partners was examined using the centrality index. In all the relevant years, Iran has had a middle rank among the five member countries of the Eurasian Economic Union. This is both in export and import networks. This means that Iran's trading partners in the Union have had fewer commercial relations with one another than those of the other Union countries (except the Russian Federation and Kazakhstan). According to the review of this index in 2021, the Russian Federation and Kazakhstan play a crucial role in the trade network of primary agricultural products within the Eurasian Economic Union by exporting and importing primary agricultural products. In fact, according to the results obtained based on the indicators of Iran's centrality in the Eurasian Economic Union trade network in 2000 and 2021, Iran was not a central country and has consistently ranked in the middle. Its position was weaker in imports than in exports. Russia and Kazakhstan had a much better situation than Iran, and the three countries of Kyrgyzstan, Armenia, and Belarus had a worse situation. Table 3 shows the indicators calculated for Iran and the five countries of the Eurasian Economic Union in the export and import network of primary agricultural products.

Table 3. Calculated Indicators for Iran and the Five Countries of the Eurasian Economic Union in the Export and Import Network

Belarus	**Armenia**	**Kyrgyzstan**	**Kazakhstan**	**Russian Federation**	**Iran**	**Iran's rank**	**Year**	**Index**	**Flow**
4	3	5	6	10	4	4	2000	Degrees of each vertex	Export
6	6	4	8	8	4	5	2021		
0	0	0	0.5	13	0.5	3	2000	Betweenness centrality	
0	0	0	1.5	1.5	0	5	2021		
0.6	0.6	0.8	0.9	1	0.7	4	2000	Eigenvector centrality	
0.9	0.9	0.7	1	1	0.9	3	2021		
4	3	5	6	10	4	4	2000	Degrees of each vertex	Import
6	6	4	8	10	6	3	2021		
0	0	0	0.5	13	0.5	3	2000	Betweenness centrality	
0.66	0.66	0	2.66	5.33	0.66	3	2021		
0.66	0.66	0.8	0.9	1	0.7	4	2000	Eigenvector centrality	
0.8	0.8	0.7	0.9	1	0.8	3	2021		

Source: Research finding.

Conclusion

In this research, by using complex networks and a new approach, information was extracted about the structure of the export and import network of primary agricultural products in the Eurasian Economic Union so that the trade of primary agricultural products in the Eurasian Economic Union could be treated as a complex system and its behavior investigated. The export and import networks were constructed using bilateral trade statistics of 6 countries for 2000 and 2021. The characteristics of these networks were calculated. According to the results of export and import networks in the considered years, the network follows a power-law degree distribution and has a high clustering coefficient. These results confirm the theory that the trade network of the union has the characteristics of complex networks. Also, according to the results extracted for Iran, Iran is not a significant actor in these networks. Based on the calculated centrality indices, Iran has always been in the middle of the member countries in terms of rank. On the other hand, regarding the number of trading partners, Iran’s position is better than the average of the selected countries. Also, the examination of Iran’s trading partners shows that, on average, they have few commercial relations with one another, and it should be noted that the results obtained confirm the previous studies, including the study of Fagiolo et al. (2008), namely that countries with many trade relations are more connected to countries that have few trading partners. Also, according to the findings of this research, there is a positive correlation between the degree strength of each vertex and the clustering coefficient; This means that countries with higher strength degree are more likely to form strong trade clubs. Also, the results of the model are in accordance with the studies of Chen and Zhang (2022), Chris et al. (2021), and Berkum (2021), which show that the growth and development of trade have a positive and significant effect on the food security of countries.

These results are critical for Iran as a country affected by economic sanctions. By increasing the number of trading partners and diversifying its partner countries, Iran’s role and importance in the trade network for primary agricultural products can increase, enabling it to provide more stable food security. On the other hand, if Iran faces food-security problems, the ability to transfer some of the effects of crises to other countries can reduce their impact on the country’s food security. For this reason, it is suggested that Iran’s role in the Eurasian Economic Union trade network be strengthened by increasing the number of trading partners so that Iran becomes a key player in this network.

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