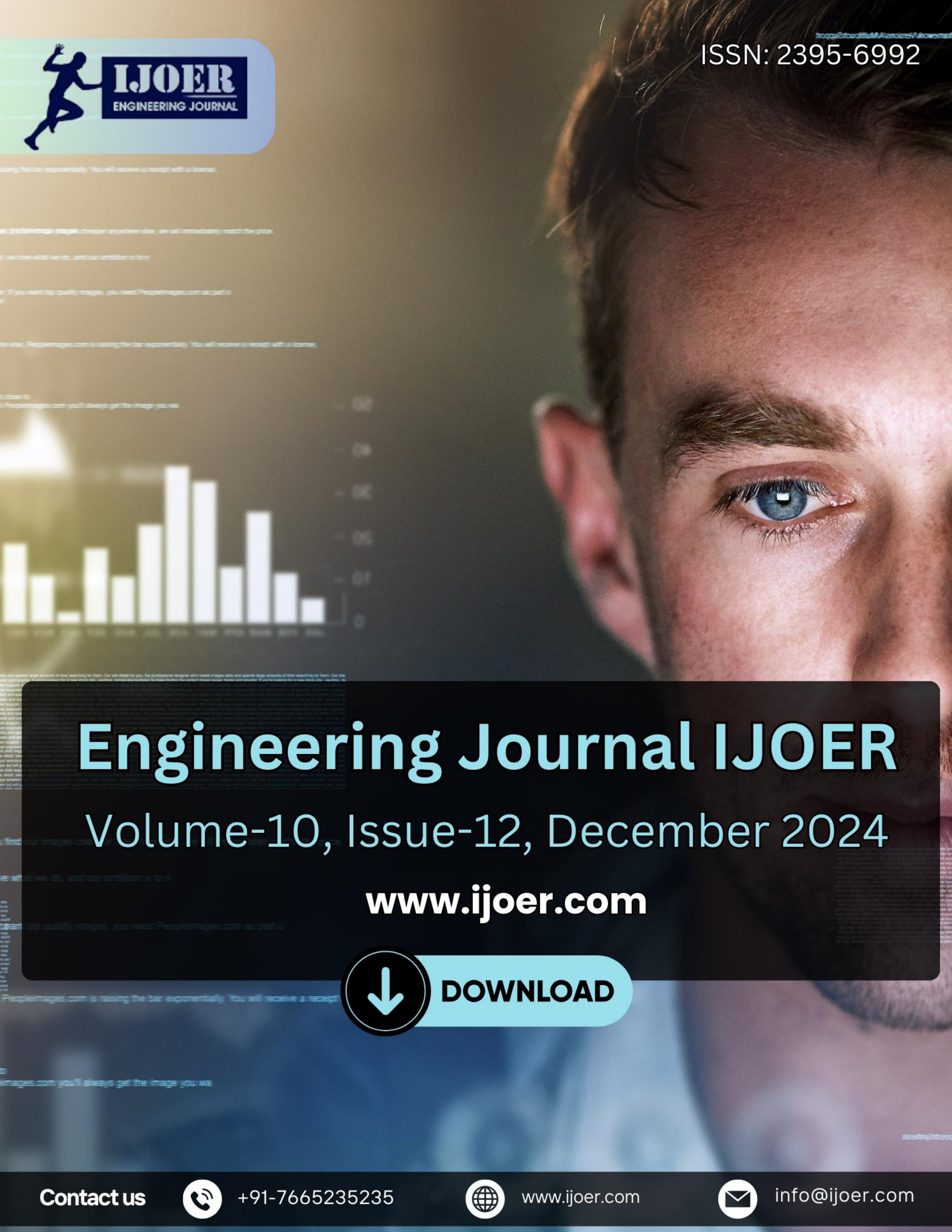

IJOER
ENGINEERING JOURNAL
ISSN: 2395-6992
Engineering Journal IJOER
Volume-10, Issue-12, December 2024
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Preface

We would like to present, with great pleasure, the inaugural volume-10, Issue-12, December 2024, of a scholarly journal, *International Journal of Engineering Research & Science*. This journal is part of the AD Publications series *in the field of Engineering, Mathematics, Physics, Chemistry and science Research Development*, and is devoted to the gamut of Engineering and Science issues, from theoretical aspects to application-dependent studies and the validation of emerging technologies.

This journal was envisioned and founded to represent the growing needs of Engineering and Science as an emerging and increasingly vital field, now widely recognized as an integral part of scientific and technical investigations. Its mission is to become a voice of the Engineering and Science community, addressing researchers and practitioners in below areas:

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Each article in this issue provides an example of a concrete industrial application or a case study of the presented methodology to amplify the impact of the contribution. We are very thankful to everybody within that community who supported the idea of creating a new Research with IJOER. We are certain that this issue will be followed by many others, reporting new developments in the Engineering and Science field. This issue would not have been possible without the great support of the Reviewer, Editorial Board members and also with our Advisory Board Members, and we would like to express our sincere thanks to all of them. We would also like to express our gratitude to the editorial staff of AD Publications, who supported us at every stage of the project. It is our hope that this fine collection of articles will be a valuable resource for *IJOER* readers and will stimulate further research into the vibrant area of Engineering and Science Research.

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Analysis of Influencing Factors of Food Trade Network of Countries along the Belt and Road

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Received: 04 December 2024/ Revised: 11 December 2024/ Accepted: 21 December 2024/ Published: 31-12-2024

Abstract— *Against the backdrop of globalization, China launched the "Belt and Road" initiative in 2013. Food trade has thus become one of the key areas of cooperation among countries. As a fundamental material guarantee for human survival, the importance of food is self-evident.*

This paper focuses on the grain trade volumes of the 66 member countries of the BRI at its inception, analyzing the structure and influencing factors of the grain trade network from 2003 to 2022 using network centrality analysis and Temporal Exponential Random Graph Models (TERGM).

Using the aforementioned methods, this paper draws the following main conclusions: (1) China shifted from being a grain exporter to a grain importer, with a significant disparity between imports and exports. (2) Russia and Turkey played dual roles in the grain trade network, acting as both major exporters/importers and key intermediary countries. India, Russia, and Ukraine were the top grain exporters, while China emerged as the largest grain importer. (3) Variables such as GDP, total population, grain production, and total fertility rate had a significant impact on the trade network of BRI countries before and after 2013.

Keywords— The Belt and Road; Food Trade Network; TERGM.

I. INTRODUCTION

Against the backdrop of globalization, the "Belt and Road" initiative serves as a transnational economic cooperation framework that has a profound impact on promoting food trade among countries along its route. This initiative, by strengthening infrastructure construction and enhancing regional connectivity, provides convenient conditions for food trade, which helps to alleviate global food security issues.

Food security is a significant strategic issue concerning national security. Research on food trade issues remains a hot topic at present. Chen Yiwen and Li Erling[1] combined social network analysis with spatial econometric analysis to deeply analyze the structural characteristics of the food trade network between China and other countries participating in the Belt and Road initiative, and identified that China's food trade pattern with these countries has shifted from being export-oriented to import-oriented. Du Hangcheng[2] used stochastic frontier analysis technology to construct a stochastic frontier gravity model and a trade inefficiency model, aiming to explore the potential capabilities of China and the countries of the Regional Comprehensive Economic Partnership (RCEP) in the field of agricultural product trade. The research results show that China's economic growth and the expansion of the population scale of trading partner countries have a significant positive impact on China's export of agricultural products to RCEP member countries. Xu Chuan-chen and Jiang Han[3] used the CONCOR method for non-overlapping community analysis of the international food trade matrix and found that the distribution of national communities in the international food trade network has certain characteristics: some communities are completely characterized by geography, some communities completely break through geographical restrictions, and some communities have both characteristics. The members of the communities will change over time, and the number of community member countries in different years is roughly the same.

In terms of network influence factors, Wu Gang[4] used the Exponential Random Graph Model (ERGM) to examine the impact of international human relations networks on international trade networks from different dimensions and over different years.

The results showed that a country's position in the human relations network, as well as its economic scale, significantly influences its status in the trade network. Han Dong and Li Guangsi[5] conducted a structural analysis of the trade network of countries along the Belt and Road, and analyzed the impact mechanism of the block model on the network, finding that China's participation and discourse power in regional food trade have increased, and culture, exchange rates, etc., are the main factors affecting the trade pattern between countries.

This paper primarily employs network centrality analysis and the Temporal Exponential Random Graph Model (TERGM) model to analyze the food trade network among countries along the Belt and Road. Based on the construction of the food trade network for Belt and Road countries, the paper analyzes the structural characteristics of the network as well as the influencing factors.

II. RESEARCH METHODS AND DATA SOURCES

2.1 Construction of the Food Trade Network among BRI countries:

A trade network is constructed based on the grain trade between the 66 countries along the BRI. In this network, countries are represented as nodes, and trade relations between them are represented as directed and weighted edges, forming the directed weighted grain trade network of the BRI countries, denoted as $G = (N, E, W)$. Here, G is a directed weighted network, N is a set of nodes containing the 66 countries involved in the BRI; E is a set of edges formed by pairs of countries that have trade relations; and W is a set of weights w_{ij} assigned to each edge, where w_{ij} equals the grain trade volume from country i to country j, which is also equal to the grain trade volume from country j to country i. If there is no trade relationship between two countries, then $w_{ij} = 0$.

2.2 Network Centrality Indicators:

The network centrality of network used in this paper are shown in Table 1.

TABLE 1
NETWORK CENTRALITY INDICATORS

indicators	Formula	Description
Out-degree centrality	$C_{in}(i) = \frac{D_{in}(i)}{n-1}$	$C_{in}(i)$ represents the out-degree centrality of node i, $D_{in}(i)$ represents the out-degree of node i, which is the number of connections from node i to other nodes.
In-degree centrality	$C_{out}(i) = \frac{D_{out}(i)}{n-1}$	$C_{out}(i)$ represents the in-degree centrality of node i, $D_{out}(i)$ represents the in-degree of node i, which is the number of connections directed towards node i from other nodes.
Betweenness centrality	$C_B(i) = \frac{2\sum_{j<k} g_{jk}(i)/g_{jk}}{(n-1)(n-2)}$	$C_B(i)$ represents the betweenness centrality of node i, g_{jk} represents the total number of shortest paths between node j and node k, and $g_{jk}(i)$ represents the number of paths that pass through node i on the shortest path between node j and node k.
Out-trade Intensity	$T_{out}(i) = \sum_j w_{ij}$	$T_{out}(i)$ represents the export trade intensity of country i.
In-trade Intensity	$T_{in}(i) = \sum_j w_{ji}$	$T_{in}(i)$ represents the import trade intensity of country i.

2.3 TERGM:

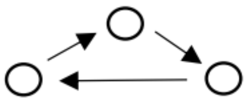
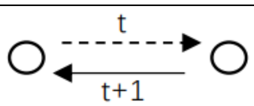
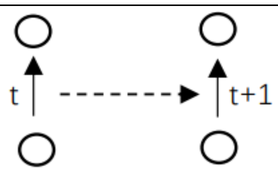
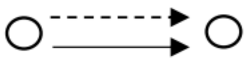
Compared to traditional econometric models, Exponential Random Graph Models (ERGM) place greater emphasis on the dependencies among relationships within a network, while also considering the influence of actor attributes and external environments on network structure[6]. Although ERGM can effectively analyze static cross-sectional network data at a specific point in time, it is not suitable for analyzing dynamic changes in network data. When examining network changes, it is essential to take into account how historical network configurations impact the current network. TERGM analyze multiple network periods as a whole, fully considering the influence of historical network patterns. The basic principle is as follows: Let there be a series of network sets $G_t = (V_t, E_t)$ (where V_t represents the nodes in the network at time t and E_t represents the edges in the network at time t.) A specific network configuration at time t is denoted as y^t. Based on the principles of discrete-time Markov chains, a k-order Markov-dependent TERGM is defined, where the configuration of the network at time t depends only on the network configurations of the previous k periods:

$$P\left(Y^t = y^t \mid Y^{t-k},...,Y^{t-1},\theta\right) = \frac{\exp\left(\sum_H \theta_H g\left(y^t, y^{t-1},...,y^{t-k}\right)\right)}{c\left(\theta, y^{t-k},...,y^{t-1}\right)} \tag{1}$$

In which, c is a standardization constant; H represents the network attributes that affect the formation of network relationships, namely actor-relationship effects, network endogenous effects, and exogenous network relationship effects; $g(y)$ is the mathematical expression of this attribute; θ_H is the coefficient of this attribute, and the coefficient vector θ is composed of θ_H.

The main variables in TERGM are shown in Table 2.

TABLE 2
DESCRIPTION OF THE MAIN VARIABLES IN TERGM

Variables	Structural diagram	Description
Edge		The number of edges in a network.
Outdegree effect		Test whether countries with certain attributes in the network establish export relationships with foreign countries.
Indegree effect		Test whether countries with certain attributes in the network establish import relationships with foreign countries.
Heterogeneity		Test whether countries with the same attributes in the network are inclined to establish trade relationships.
Cyclicity		A cyclic relationship among three nodes in the network, where node i is connected to node j, node j is connected to node k, and node k is connected to node i.
Delayed Reciprocity		A pair of nodes act as both senders and receivers to each other in the network.
Stability		Test whether the network structure in period $t-1$ affects the network structure in period t.
Covariate network		Test whether the existence of relationships in other networks makes it easier to generate trade relationships.

2.4 Research Subjects and Data Sources

Since the proposal and implementation of the BRI, several countries have joined the initiative. To ensure consistency in the selected research countries, this study focuses on the 65 member countries identified by the Chinese Ministry of Foreign Affairs when the BRI was first proposed (including China, making a total of 66). The time frame for the study is from 2003 to 2022.

To ensure data consistency, this study adopts the definition of food as established by the Food and Agriculture Organization (FAO) and uses the HS codes set by the Customs Cooperation Council (now known as the World Customs Organization) as a uniform accounting standard for calculating the food trade volume of BRI countries. The data is sourced from the United Nations Commodity Trade Database, specifically the HS10-Cereals data, which includes wheat and mixed wheat, rye, barley, and others.

III. OVERVIEW OF GRAIN TRADE AMONG BRI COUNTRIES AND NETWORK CENTRALITY ANALYSIS

3.1 Overview of Grain Trade Between China and Other BRI Countries:

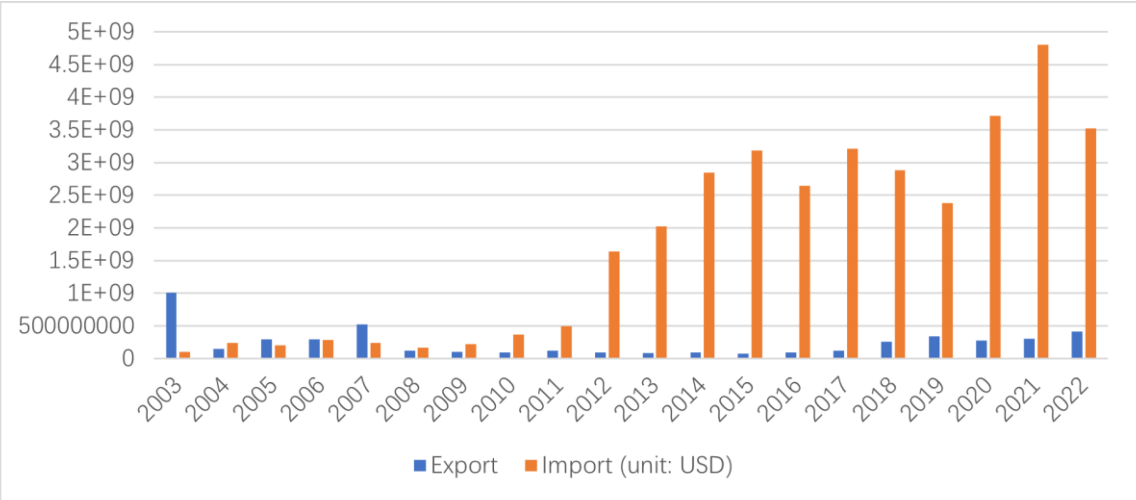


FIGURE 1: China's grain trade with other BRI countries from 2003 to 2022

Based on Figure 1, a comparative analysis of China's grain imports and exports reveals the following key conclusions:

1) Imports have consistently exceeded exports since 2008. From 2003 to 2007, China was a net exporter of grain. However, starting from 2008, China's grain imports have consistently surpassed its exports. This indicates that, following the global financial crisis, China has maintained a trade deficit in grain with BRI countries, demonstrating its strong demand for grain supplies from these nations. In terms of growth, China's grain imports from BRI countries increased from $98,791,778 in 2003 to $3,524,605,300 in 2022, a staggering rise of approximately 3468%. By contrast, exports during the same period dropped by around 59%, from $1,008,648,721 to $417,065,565. Although exports saw significant growth after 2004, the base and upward trend of imports were much more pronounced.

2) Exports are volatile, while imports are relatively stable. China's grain exports showed considerable fluctuations, following a rise-fall-rise pattern: exports peaked in 2007 but plummeted significantly in 2008. In the following years, exports remained at relatively low levels until growth resumed in 2016. In contrast, grain imports exhibited a steady upward trend, with only minor fluctuations in certain years, reflecting China's consistent demand for grain, especially as imports became a vital tool for stabilizing the domestic market in response to supply shortages or price volatility.

3) Widening gap between imports and exports. From 2003 to 2022, the gap between China's grain imports and exports widened significantly. In 2003, imports were approximately $900 million less than exports, but by 2022, imports exceeded exports by roughly $3.1 billion. Although there has been some recovery in export levels in recent years, the faster pace of import growth has led to a progressively widening trade gap.

3.2 Analysis of the Network Centrality of the BRI Countries' Grain Trade Network:

This study focuses on the directed network of grain trade among BRI countries for six selected years: 2003, 2008, 2013, 2018, 2021, and 2022. After calculating the network centrality of the directed network for BRI countries grain trade from 2003 to 2022, the top-ranking countries for each indicator were visualized.

3.2.1 Out-degree and In-degree Centrality:

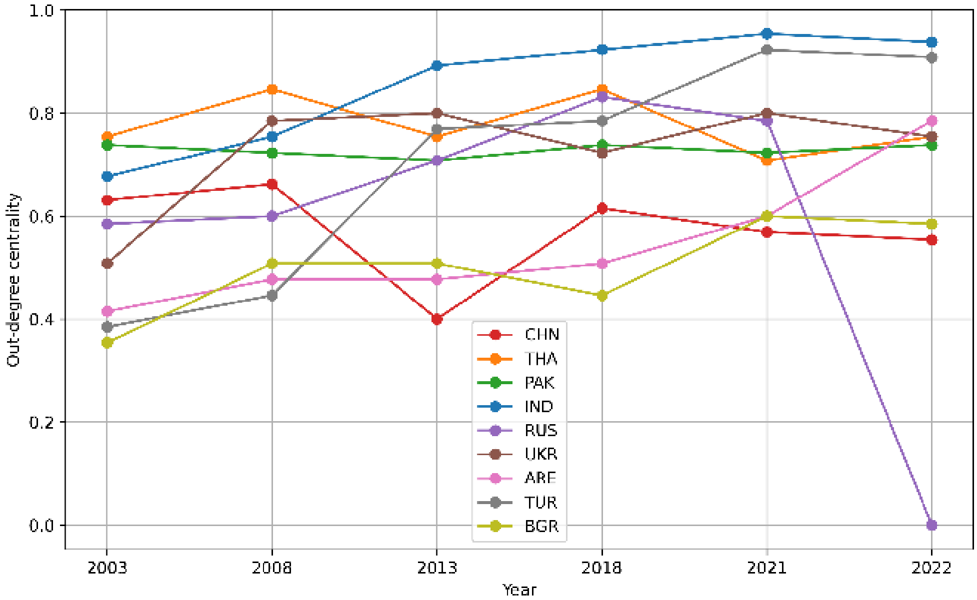


FIGURE 2: Out-degree centrality of major Belt and Road countries from 2003 to 2022

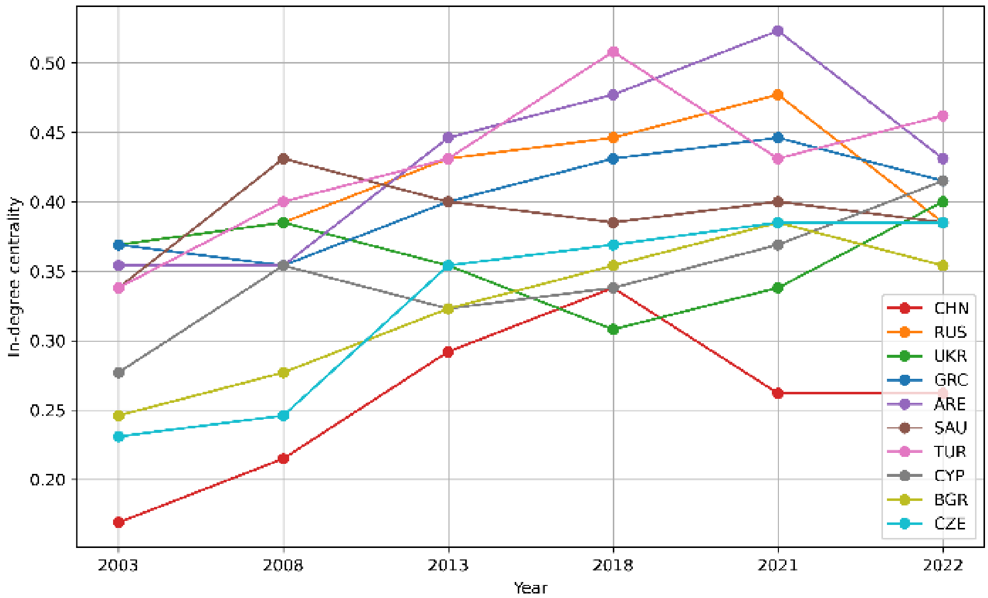


FIGURE 3: In-degree centrality of major Belt and Road countries from 2003 to 2022

According to Figure 2 and Figure 3, India has consistently held the highest out-degree centrality position since 2013, but its in-degree centrality is relatively low, indicating that the number of countries India exports food to exceeds the number of countries from which it imports food. Thailand's out-degree centrality ranked first in both 2003 and 2008, but its position has gradually been surpassed by India. Turkey's out-degree centrality began to rank prominently after 2013, particularly in 2021 and 2022, when it was ranked second. Turkey also demonstrated strong in-degree centrality in 2008, 2013, 2018, and 2022, peaking in 2018, indicating that it is both an important food exporter and importer. The out-degree and in-degree centrality of Russia and Ukraine have generally remained among the highest from 2003 to 2022, showing that these two countries have strong export capacities as well as certain import demands in food trade. The United Arab Emirates has a relatively low out-degree centrality but has maintained its position among the top two in in-degree centrality since 2013, reaching its peak in 2021. Greece has a lower out-degree centrality compared to other countries but has ranked among the top in in-degree centrality in multiple years. In summary, India, Turkey, Thailand, and Ukraine have a larger number of exporting trade partners, while the United Arab Emirates and Turkey have more importing trade partners. Both Turkey and Russia have a significant number of exporting and importing trade partners, indicating their important positions in the food trade network of BRI countries.

3.2.2 Betweenness Centrality:

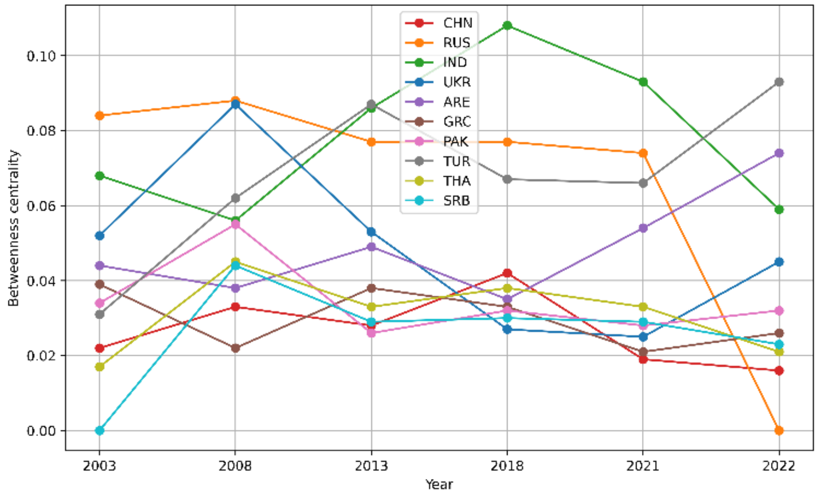


FIGURE 4: Betweenness centrality of major Belt and Road countries from 2003 to 2022

Betweenness centrality reflects a country's mediating role in the trade network, indicating the frequency with which that country acts as an intermediary or bridge between other countries. Countries with high betweenness centrality typically occupy important hub positions within the trade network, possessing strong influence and coordination capabilities. As shown in Figure 4, an analysis of the betweenness centrality in the food trade network of BRI countries reveals a "power-law distribution", meaning that a few countries have high trade connectivity while many other countries have low trade connectivity. These few countries with higher betweenness centrality exert considerable control over the overall trade network. From a general trend perspective, Russia, India, and Turkey have consistently ranked at the top in multiple years, serving as important mediators in the food trade network. The United Arab Emirates has shown an overall upward trend in betweenness centrality, indicating that its mediating role in the trade network is continuously strengthening, reaching a peak of 0.074 in 2022, second only to Turkey.

Combining the analyses of out-degree centrality and in-degree centrality, Russia and Turkey emerge as both major exporters and importers in the food trade network, while also serving as key intermediary countries, playing multiple important roles.

3.2.3 Out-trade Intensity:

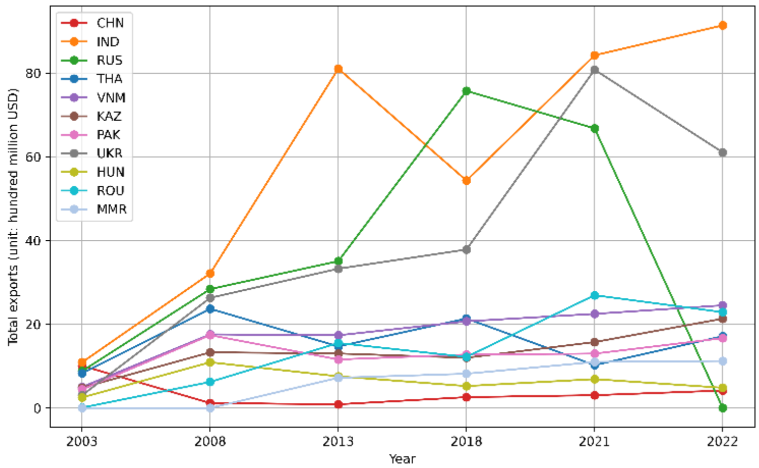


FIGURE 5: Total food exports of major Belt and Road countries from 2003 to 2022

As shown in Figure 5, between 2003 and 2022, particularly after the BRI trade agreement came into effect in 2013, the total grain exports of India, Russia, and Ukraine far exceeded those of other countries. India maintained a leading position throughout this period, with its total exports growing from $1.091 billion in 2003 to $9.136 billion in 2022. Following the outbreak of the Russia-Ukraine war in 2022, Russia suspended its grain exports. During this time, Ukraine's grain exports significantly increased, especially in 2021, when its total exports reached $8.076 billion, demonstrating strong growth momentum. Other countries, such as Vietnam and Romania, also showed a gradual upward trend in their grain export volumes.

3.2.4 In-trade Intensity:

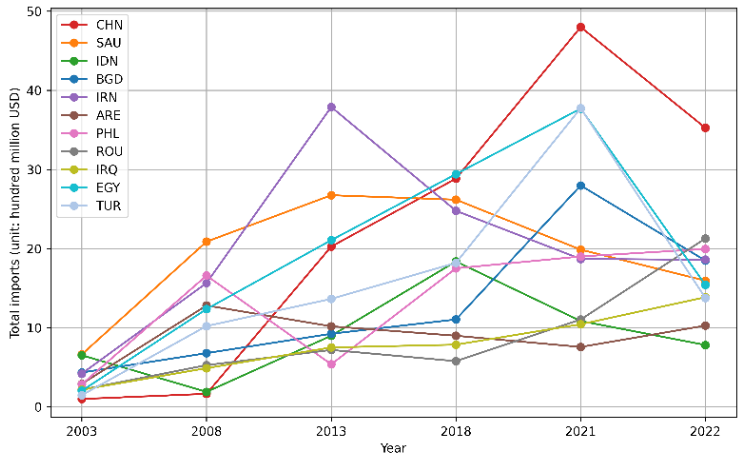


FIGURE 6: Total food imports of major Belt and Road countries from 2003 to 2022

As shown in figure 6, from the perspective of import trade intensity, Saudi Arabia consistently maintained a leading position in total imports in 2003 and 2008, with totals of $662 million and $2.087 billion, respectively, indicating its strong import demand and market influence during this period. After entering 2018, China's total imports grew rapidly, reaching $2.884 billion in 2018, and leading the rankings in 2021 with total imports of $4.799 billion. In 2022, China maintained its top position with total imports of $3.525 billion. This demonstrates China's increasingly important role in the grain trade among BRI countries. Except for 2013, when Iran ranked first with $3.789 billion, its grain imports remained relatively stable in other years. The Philippines and Egypt gradually increased their total imports during this period. For instance, the Philippines entered the top ten in 2021 with total imports of $1.868 billion, while Egypt surged to second place in 2022 with total imports of $1.994 billion, showing significant growth momentum. Over time, emerging markets began to rise, with other countries such as Romania, Bangladesh, and Turkey also starting to occupy more important positions in total imports. For example, in 2022, Romania ranked second with total imports of $2.127 billion, highlighting the importance of emerging markets in BRI grain trade.

Overall, from 2003 to 2022, India and China demonstrated high trade demand in exports and imports, respectively, becoming the most prominent import and export trading nations among BRI countries.

IV. ANALYSIS OF THE DYNAMIC EVOLUTION FACTORS OF FOOD TRADE NETWORKS AMONG BRI COUNTRIES

4.1 Data Sources and Variable Selection:

Based on existing literature[7][8], this study selects seven indicators for analysis: economic development level, total population, grain production, total fertility rate (the number of births per woman), geographical distance, geographical proximity, and official language. The economic development level is measured by the GDP (in current US dollars) of each country; geographical distance is measured by the spherical distance between the capitals of the countries; geographical proximity is determined by whether the territories of the two countries share a border, where a shared border is assigned a value of 1, and no border is assigned a value of 0. The official language is represented using a binary matrix, where a value of 1 indicates that both countries speak the same language, and 0 indicates otherwise. All data are sourced from the World Bank or the CEPII database. All data have undergone range normalization, and missing values have been filled using methods such as mean substitution. To avoid self-looping in the network, the geographical distance between the same country is set to 0.

Based on existing research[9][10] and in conjunction with the data collected for this paper, a trade threshold of ten million US dollars is selected to construct a binary trade matrix: if the trade volume exceeds ten million US dollars, the corresponding element in the trade matrix is set to 1, otherwise it is 0. Subsequently, an analysis of the influencing factors is conducted on the directed trade network constituted by the binary trade matrix.

4.2 TERGM Analysis of Trade Networks Before and After 2013:

To explore the evolution of food trade networks among BRI countries before and after the signing of the BRI agreement in 2013, we divide the time span from 2003 to 2022 at the year 2013, analyzing it as two periods: 2003-2013 and 2013-2022.

Due to the large time span of the research data and the numerous explanatory variables involved, including data for each year in the model could result in potential disruptions during the simulation process. Therefore, based on a review of relevant literature[11][12], we select research years at one-year intervals, as detailed in Table 3.

TABLE 3
SELECTED RESEARCH YEARS AROUND 2013

Time period	Research years					
2003-2013	2003	2005	2007	2009	2011	2013
2013-2022	2013	2015	2017	2019	2021	2022

4.2.1 Fitting Results Analysis:

We selected three types of explanatory variables-actor-relation effects, exogenous relation effects, and network endogenous effects-to model the grain trade networks for the two time periods of 2003-2013 and 2013-2022 using TERGM. The results are presented in Table 4.

TABLE 4
TERGM FITTING RESULTS AROUND 2013

	Explanatory variables	2003-2013	2013-2022
Actor-relation effects	**Sending effects**		
	GDP	1.35 (4.42)	5.47 (3.46)
	Total population	-7.66 (1.59) ***	-5.78(1.19) ***
	Grain production	22.69(3.12) ***	14.23(2.21) ***
	Total fertility rate	-1.83 (0.41) ***	-1.38 (0.52) **
	Receiving effects		
	GDP	32.34 (4.52) ***	16.42 (3.38) ***
	Total population	-1.31 (1.72)	-4.81 (1.48) **
	Grain production	-0.61 (3.46)	4.29 (2.42)
	Total fertility rate	0.44 (0.42)	1.17 (0.54) *
	Heterophily		
	GDP	-9.18 (4.37) *	-12.02 (3.40) ***
	Total population	7.17 (1.40) ***	5.05 (1.10) ***
	Grain production	-17.41 (2.86) ***	-7.55 (2.01) ***
	Total fertility rate	0.68 (0.47)	-0.41 (0.62)
Exogenous relation effects	**Covariate network**		
	Geographic distance network	-2.81 (0.31) ***	-1.77 (0.27) ***
	Geographic proximity network	0.65 (0.16) ***	0.69(0.17) ***
	Official language network	-0.12 (0.20)	-0.40 (0.24)
Network endogenous effects	**Structural dependence**		
	Cyclic closure	-0.66 (0.20) ***	-0.18(0.12)
	Temporal dependence		
	Delayed reciprocity	0.44 (0.24)	0.61 (0.20) **
	Stability	2.40 (0.06) ***	2.60 (0.05) ***
	Edge	-1.15 (0.14) ***	-1.52 (0.15) ***

Note:*, **, and *** indicate significance at the 5%, 1%, and 0.1% levels, respectively; standard errors are given in parentheses. The same applies to the following.

As shown in Table 4, regarding actor-relation effects:

1) **Sending effects:** GDP was not significant in either period, indicating that GDP had no significant impact on the sending of grain trade. Population size and total fertility rate were both negative and significant across the two periods, showing that countries with larger populations and higher fertility rates were less likely to engage in grain exports. Grain production was positive and significant in both periods, indicating that countries with higher grain production were more inclined to export grain. However, after 2013, this effect weakened, with the coefficient dropping from 22.69 to 14.23.
2) **Receiving effects (importing grain):** GDP was positive and significant in both periods, showing that countries with higher GDP were more likely to import grain. However, this effect weakened after 2013, with the coefficient decreasing from 32.34 to 16.42. Population size was insignificant during 2003-2013, but became negative and significant during 2013-2022, indicating that countries with larger populations were less inclined to import grain after 2013. A possible explanation is that larger populations provide more labor for grain production, reducing dependence on imports. Grain production was insignificant in both periods for importing effects, indicating that it had no clear impact on whether a country imported grain. Total fertility rate was insignificant in 2003-2013 but became positive and significant in 2013-2022, indicating that countries with higher fertility rates were more likely to import grain after 2013.
3) **Heterophily:** GDP was negative and significant in both periods, showing that grain trade was less common between countries with large GDP differences. This effect strengthened after 2013. Population size was positive and significant in both periods, indicating that grain trade was more common between countries with larger population differences, though the effect weakened after 2013. Grain production was negative and significant in both periods, showing that grain trade was less common between countries with large differences in grain production, though the effect weakened after 2013. Total fertility rate had no significant heterophily effect in either period.

For exogenous relation effects:

1) Geographic distance was negative and significant in both periods, showing that countries further apart were less likely to trade grain, reflecting a negative impact of geographic distance on trade. However, the coefficient increased after 2013, suggesting that the negative effect weakened, likely due to the BRI, which promoted grain trade among participating countries and shortened trade distances.
2) Geographic proximity was positive and significant in both periods, with a slight increase in effect after 2013, indicating that neighboring countries were more likely to engage in grain trade compared to non-neighboring countries, corroborating the findings on geographic distance.
3) Official language had a suppressive effect on grain trade in both periods but were not significant, indicating that language did not have a significant impact on trade among BRI countries.

Regarding endogenous network effects:

1) Cyclic closure was negative and significant from 2003 to 2013, but insignificant after 2013, indicating that cyclic closure only had a suppressive effect on grain trade before 2013.
2) Delayed reciprocity was insignificant in 2003-2013 but became positive and significant in 2013-2022, showing that delayed reciprocity began promoting grain trade after 2013. Unidirectional grain import-export relationships between countries contributed to the formation of later bilateral trade.
3) Stability was positive and significant in both periods, with the coefficient increasing after 2013, indicating that the grain trade network has become increasingly stable over time.

By comparing the two periods (2003-2013 and 2013-2022) for grain trade networks among BRI countries, the following insights can be drawn:

1) The four variables-GDP, population size, grain production, and total fertility rate-maintained consistent directions for both sending and receiving effects across the two periods, though there were changes in significance and strength.
2) For heterophily effects, GDP's suppressive effect on grain trade strengthened after 2013, while the suppressive effect of differences in grain production weakened after 2013. The positive effect of population size differences on trade also weakened after 2013.

3) In terms of exogenous relation effects, the negative impact of geographic distance on grain trade weakened after 2013, while the positive effect of geographic proximity slightly increased. The influence of official language on grain trade remained insignificant in both periods.

4) For endogenous network effects, cyclic closure ceased to be significant after 2013, while delayed reciprocity became significantly positive, suggesting more reciprocal trade behavior in the post-2013 grain trade network. Stability remained positive and significant across both periods, indicating that the grain trade network structure has become more stable.

4.2.2 Goodness of Fit Test:

The goodness-of-fit for the TERGM models in both time periods, before and after 2013, is tested using the results in Table 4. Based on the estimated parameters from Table 4, 100 networks were simulated for both the 2003-2013 and 2013-2022 periods. The key features of these simulated networks were then visualized alongside the real network features, as shown in Figure 7 and Figure 8.

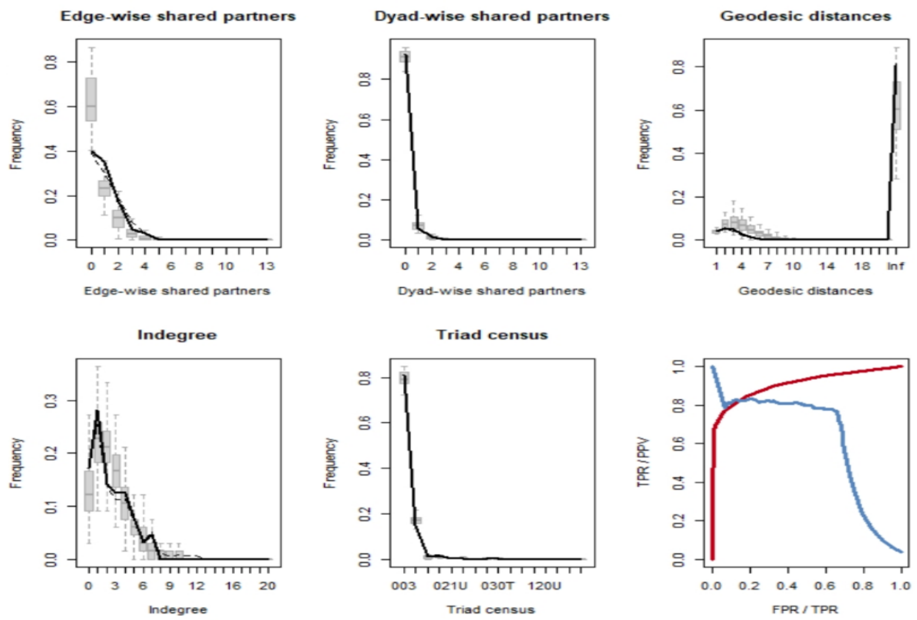


FIGURE 7: 2003-2013 TERGM Goodness-of-Fit Test

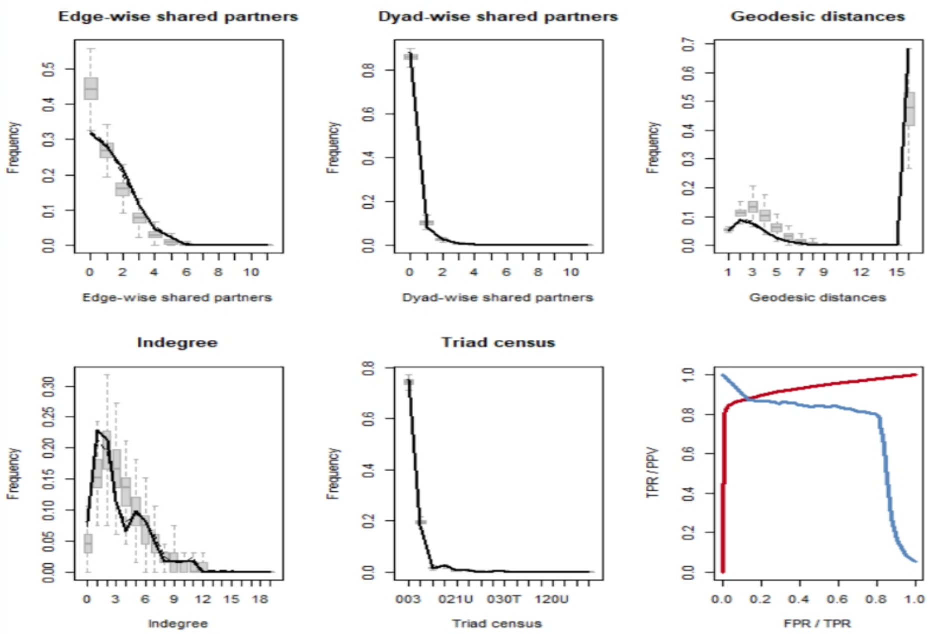


FIGURE 8: 2013-2022 TERGM Goodness-of-Fit Test

In the boxplots drawn from the simulated network feature values, the closer the median of the boxplot is to the observed feature values, the better the model's fit[13]. In the final subplot, the red line on the left represents the ROC curve. From Figure 7 and Figure 8, it can be seen that both the 2003-2013 and 2013-2022 TERGMs exhibit good fit. Additionally, the fit of the 2013-2022 TERGM is slightly better than that of the 2003-2013 model.

4.2.3 Robustness Test:

To test the robustness of the models in Table \ref{table5}, and drawing from relevant literature and methods, the MCMC MLE estimation method used for the 2003-2013 and 2013-2022 periods in Table 4 was replaced with the bootstrap MPLE method, as shown in Table 5 [7]**Error! Reference source not found.**. The final results indicate that the signs of all variable coefficients remained unchanged, and the estimation results from both methods were very similar. Therefore, the TERGM model fitting results for the 2003-2013 and 2013-2022 periods in Table 4 demonstrate good robustness.

TABLE 5
TERGM FITTING RESULTS OF BOOTSTRAP MPLE METHOD AROUND 2013

	Explanatory variables	2003-2013	2013-2022
Actor-relation effects	**Sending effects**		
	GDP	1.36 *	4.95 *
	Total population	-7.82 *	-5.68 *
	Grain production	23.14 *	14.09 *
	Total fertility rate	-1.82 *	-1.40 *
	Receiving effects		
	GDP	32.80 *	16.34 *
	Total population	-1.44 *	-4.50 *
	Grain production	-0.39 *	3.57 *
	Total fertility rate	0.46 *	1.18 *
	Heterophily		
	GDP	-9.89 *	-11.60 *
	Total population	7.15 *	4.97 *
	Grain production	-17.45 *	-7.39 *
	Total fertility rate	0.69 *	-0.43 *
Exogenous relation effects	**Covariate network**		
	Geographic distance network	-2.85 *	-1.76 *
	Geographic proximity network	0.63 *	0.69 *
	Official language network	-0.13 *	-0.40 *
Network endogenous effects	**Structural dependence**		
	Cyclic closure	-0.68 *	-0.10 *
	Temporal dependence		
	Delayed reciprocity	0.57 *	0.58 *
	Stability	2.40 *	2.60 *
	Edge	-1.15 *	-1.53 *

V. CONCLUSIONS

This article focuses on the grain trade volumes of the 66 countries involved in the BRI at its inception, covering the period from 2003 to 2022. Using social network analysis, the study examines the structural characteristics of the trade network formed by these 66 countries. The DI-SIM co-clustering algorithm is employed to categorize the import and export relationships within the network, while the TERGM is used to explore the influencing factors of the grain trade network among BRI countries. The main conclusions drawn from the analysis are as follows:

1) **China's Import and Export Trade:** From 2003 to 2007, China was a grain-exporting country. However, post-2008, China's grain imports consistently exceeded its exports, and the trade gap between imports and exports gradually widened: in 2003, imports were about $900 million less than exports, but by 2022, imports exceeded exports by approximately $3.1 billion.
2) **Network Centrality:** Following the signing of the BRI agreement, the out-degree centrality of India and Turkey significantly increased, with India consistently maintaining the highest out-degree centrality. Since 2003, the in-degree centrality of the UAE and Turkey has remained relatively high. India, Thailand, and Ukraine have a considerable number of grain export partners, while the UAE has numerous grain import partners. The in-degree centrality among BRI countries generally remains low, with Russia, India, and Turkey being the most important intermediary countries, possessing substantial network influence and coordination abilities. The intermediary role of the UAE has gradually strengthened since 2018. Additionally, Russia and Turkey serve as both major exporters and importers within the grain trade network, fulfilling multiple important roles. In terms of total export volumes, India, Russia, and Ukraine are the leading grain-exporting nations, with their export volumes significantly higher than those of other countries; however, in 2022, Russia ceased grain exports to other nations. China is a major grain-importing country, especially after 2018, when its grain import volume surged, making it the highest among all BRI countries.
3) **Influencing Factors of the Grain Trade Network among BRI Countries:** By comparing the grain trade networks before and after 2013, it can be observed that in both the sending and receiving effects, except for grain yield, the effects of GDP, total population, and total fertility rate maintain a consistent direction, though the significance and effect strength have changed. In terms of mismatching, greater differences in total population are more favorable for the formation of grain trade relationships between countries, while larger disparities in grain yields tend to inhibit the establishment of trade relationships. However, these promoting and inhibiting effects have weakened since 2013. Greater disparities in GDP correlate with fewer grain trade relationships between countries. The inhibiting effect of geographical distance on grain trade has diminished after 2013, while the promoting effect of geographical proximity has slightly increased, suggesting that the BRI has facilitated grain trade interactions among the countries along the route to some extent, aiding in the formation of trade relationships. Cultural concepts had a suppressive effect on grain trade before and after 2013, but it was not significant. Delayed reciprocity was not significant from 2003 to 2013, but became positive and significant from 2013 to 2022, indicating that the one-way grain import-export relationships between countries after 2013 contribute to the later formation of bilateral trade. Stability was significantly positive both before and after 2013, with the coefficient increasing after 2013, indicating that the grain trade network patterns among the countries along the route have become increasingly stable.

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