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Structural characteristics and influencing factors of agricultural trade spatial network: evidence from RCEP 15 countries

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ABSTRACT: Based on national agricultural trade panel data of Regional Comprehensive Economic Partnership (RCEP) countries from 2002 to 2020, the structural characteristics of the RCEP national agricultural trade spatial network are reconstructed by the social network analysis method in this paper. Specifically, the characteristics consist of overall characteristics, individual characteristics, core-periphery structure analysis, and block models. Moreover, the influence factors on the agricultural trade network are also examined by the QAP regression model. The conclusions are summarized as follows. Firstly, the agricultural trade in RCEP countries has significant spatial correlation, showing favorable stability and accessibility. Secondly, Australia, China, Thailand, and Vietnam are the central actor's leading position in the correlation network. While Cambodia, Laos, Myanmar, and other countries are in the marginal position. Thirdly, the network can be divided into four blocks, including the net benefit block, the two-way spillover block, the broker block, and the net spillover block. The spillover effect between the blocks is transitive. And finally, geographical distance, economic and social conditions, resource endowment, and language proximity index significantly impact the RCEP agricultural trade network structure.
Key words: RCEP, agricultural trade, network structure, influencing factors, social network analysis.

Características estruturais e fatores de influência da rede espacial do comércio agrícola: evidências de 15 países do RCEP

RESUMO: Com base nos dados do painel nacional de comércio agrícola dos países da Parceria Econômica Regional Abrangente (RCEP) de 2002 a 2020, as características estruturais da rede espacial nacional de comércio agrícola do RCEP são reconstruídas pelo método de análise de redes sociais deste artigo. Especificamente, as características consistem em características gerais, características individuais, análise da estrutura núcleo-periferia e modelos de blocos. Além disso, os fatores de influência na rede de comércio agrícola também são examinados pelo modelo de regressão QAP. As conclusões são resumidas da seguinte forma. Em primeiro lugar, o comércio agrícola nos países RCEP tem correlação espacial significativa e efeitos de transbordamento, mostrando estabilidade e acessibilidade favoráveis. Em segundo lugar, a rede pode ser dividida em quatro blocos, incluindo o bloco de benefícios líquidos, o bloco de transbordamento bidirecional, o bloco de corretagem e o bloco de transbordamento líquido. O efeito de transbordamento entre os blocos é transitivo. E, finalmente, a distância geográfica, as condições econômicas e sociais, a dotação de recursos e o índice de proximidade linguística afetam significativamente a estrutura da rede de comércio agrícola RCEP.
Palavras-chave: RCEP, comércio agrícola, estrutura da rede, fatores de influência, análise de redes sociais.

INTRODUCTION

In the context of economic globalization, agricultural trade has gradually become an important channel connecting regions with rich agricultural resources and regions with scarce resources. It not only spatially promotes the flow of agricultural products, but also further strengthens the spatial connection and economic dependence of the trading parties (HUANG et al., 2011; JAFARI Y., 2023). In the past four decades, the food self-sufficiency rate of most countries has not changed significantly, and more and more countries are using trade to balance the supply and demand of agricultural products (KINNUNEN et al., 2020). The State of Agricultural Commodity 2020, released by the Food and Agriculture Organization of the United Nations (FAO), shows that global agricultural trade has continuously grown since 1995, reaching US$1.5 trillion in 2018. With the deepening of economic globalization and the rapid development of regional integration, the role of international agricultural trade in guaranteeing global food security and sustainable use of resources is increasingly evident. Agricultural trade is further interpreted as an influential critical element of international economic and trade development.

The Regional Comprehensive Economic Partnership (RCEP) agreement was formally signed into force on November 15, 2020, after eight years

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since the ten ASEAN countries initiated negotiations in 2012. As an open regional economic partnership agreement, RCEP aims to establish a modern and high-quality Free Trade Area (FTA) for mutual benefits, especially in many aspects such as bilateral and multilateral trade, investment agreements, and technical cooperation. In the RCEP agreement, tariff and non-tariff barriers for agricultural products have been reduced, which provides an essential platform for enhancing agricultural cooperation and improving trade levels among member countries. As the basis for the national economic development of regional countries, agricultural trade has become a significant element of RCEP economic and trade exchanges. In the field of agricultural trade, the RCEP agreement has reduced tariff and non-tariff barriers to agricultural products, providing an important platform for strengthening agricultural cooperation and improving the trade level of member countries. Most of RCEP member countries are large agricultural product producers and traders, with a broad market, in the current WTO as the core of the global trade cooperation began to gradually replace regional trade cooperation, RCEP as an important carrier to promote the development of regional market free trade, but also will promote the optimal allocation of agricultural resources of member countries in the international regional market, accelerate the breakthrough of their own agricultural development, supply constraints, and then conducive to the supply and guarantee of food security in all countries in the world. From this perspective, studying the past and present of the development of agricultural trade in RCEP 15 countries will be more conducive to formulating relevant policy agreements to promote the development of agricultural trade within the region, and assist the government to adjust market and industry policies, so as to accurately promote the development of international resource links and international agricultural trade.

Meanwhile, most countries and regions have been involved in global agricultural trade and forming a tight network. The stability of agricultural trade in each country and region has a linkage effect on regional or global agricultural trade. In the background of the important impact that regional multilateral trade mechanisms have on the reform of global economic and trade rules, the upgrading of cooperation and the deepening of mutual trust among RCEP countries will have an important role in promoting the development of globalization. For agricultural trade, are the agricultural trade connections strong in this region? Is there a trade agglomeration effect? What is the trade influence of each country? Which factors have influenced the evolution of trade network structure? The study of these characteristics could help to grasp the pattern and development trend of agricultural trade in RCEP and take the initiative in dealing with complex economic trade relations and regional policy changes. It is also essential for improving the efficiency of agricultural trade and promoting trade flows among member countries. In view of this, this paper analyzes the spatial network structure characteristics of agricultural trade from 2002 to 2020 in the 15 countries of RCEP by social network analysis based on the UN COMTRADE database. Moreover, the influencing factors of the spatial network structure also have been explored. It provides a reference for decision-making on agricultural resource management and bilateral and multilateral collaboration within RCEP countries.

The essence of agricultural trade is an economic exchange that can be simply summarized as a process of supplying goods such as food to the importing country and export earnings to the producing country. Scholars have comprehensively assessed the drivers of agricultural trade in the era of globalization from different perspectives such as monetary, nutritional, and resource (MACDONALD et al., 2015). They also improved the decision-making efficiency concerning the trading system by capturing the complex biophysical and economic background of agricultural globalization (MEYFROIDT et al., 2013). Some scholars have also initialed a multi-disciplinary analysis of agricultural trade issues from various perspectives. In terms of research content, the existing literature mainly includes but is not limited to the pattern evolution of agricultural trade (ZAGHINI, 2005), the analysis of influencing factors (CHANEY, 2008; CHO, 2020), the causes of unstable growth (GUO et al., 2011), efficiency potential measurement (ZHANG et al., 2018; ALDAYA et al., 2010), and measurement of implied virtual resource (VORA, et al., 2017). In terms of research methods, the trade gravity model (HASINER & YU, 2019), CMS model (NURJIHAN I., 2011), LMDI model, revealed comparative advantage index (QINETI, 2009), trade complementarity index (LIU et al., 2020), and other index measurements have become mature approaches of conducting agricultural trade research. Moreover, in terms of research scales, they mainly focus on global (KUNIMITSU et al., 2020), unilateral (CAO et al., 2021), and bilateral (country-to-country) studies (ZHOU et al., 2019; HIRSCH & OBERHOFER, 2020), and some studies involve regional organizations such as “the belt and road”

(HU et al., 2021; ALHUSSAM et al., 2023), ASEAN (ZHAN et al., 2018; HAMID, 2017), and Central Europe (KRIVONOS & KUHN, 2019).

With the rapid development of economic globalization, the growing international trade is becoming a key factor in shaping the new global economic and political landscape (GEREFFI, 2010). Spatial network characteristics of international trade systems have become an emerging research field. SERRANO & BOGUÑÁ (2003) constructed a global trade network based on intercountry trade data in 2000, indicating that the international trade spatial network has characteristics such as small-world and scale-free properties. GARLASCHELLI & LOFFREDO (2009) and SQUARTINI et al. (2011) argued that the application of directed weighted networks could explain more completely the key attributes of global trade networks than unweighted trade networks, and introduced directed weighted networks into the analysis of the dynamic evolution of global trade networks. KONAR et al. (2011) and HAO et al. (2016) analyzed the spatial network structure of global virtual water trade and energy trade, respectively. Under the background of intensifying international trade conflicts, the global agricultural trade network has also become more complicated, influenced by changes in agricultural supply and demand patterns, trade policies, geo-politic, and other factors. However, there are still relatively few studies on this issue, and only a few scholars have analyzed its overall structural characteristics from the perspective of trade space networks. DONG et al. (2018) built a competition network of wheat trade using UN COMTRADE database. And the overall characteristics, core-periphery structure, and time evolution of the trade network are deeply studied. Some literatures also considered the complex food trade relationship as a whole system and applied the social network analysis method to describe the trade relationship of food and its derivatives (i.e., virtual water).

In summary, the existing agricultural trade literature provides an important theoretical and methodological reference for the conduct of this study. Scholars have paid attention to the analysis of spatial trade networks, but some issues have not been fully resolved. Firstly, compared with the research on total trade, industrial trade, service trade, etc., the research on the spatial correlation network of agricultural trade is insufficient. Secondly, traditional econometric models can only analyze the spatial heterogeneity of agricultural trade from the perspective of regions or countries. It is difficult to analyze the correlation characteristics and formation mechanism of the spatial network of agricultural trade from the overall level. In addition, from the perspective of the study area, the existing research also ignores the study of the export trade network of agricultural products in RCEP countries. Therefore, this study uses the data of agricultural trade in RCEP 15 countries to analyze the overall characteristics, individual characteristics, block characteristics, and the formation of influencing factors of its network structure.

MATERIALS AND METHODS

Study area

In this study, RCEP 15 countries are selected as the research objects, including three countries in East Asia (China, Japan, South Korea), ten countries in Southeast Asia (Brunei, Cambodia, Indonesia, Laos, Myanmar, Malaysia, Philippines, Singapore, Thailand, Vietnam), and two countries in Oceania (Australia, New Zealand) (Figure 1). RCEP covers about 2.27 billion people, and its GDP value is worth US$26 trillion, accounting for about 30% of the world's total. It is the Free Trade Area (FTA) with the largest trade scale and the most potential for development in the world.

Social network analysis

Social network analysis (SNA) is a quantitative method for relational data and its attributes. Because the social network analysis method can map and analyze the relationship between individuals within groups, organizations, communities, etc., and can establish connections between micro and macro, so that the analysis is more thorough and in-depth, it has gradually been applied by scholars to economic and management disciplines. In the field of trade research, some scholars have also drawn on the central theory to treat the relationship between members in the real system as a network, and use this to express the relationship between members in the real network. Therefore, this paper constructs trade network linkage, realizes the transformation of single country as a research center, describes the characteristics of the actual trade pattern to the greatest extent, and discusses the structural characteristics and influencing factors of agricultural trade spatial network of RCEP countries through overall network, individual network, block model and QAP regression.

International trade can be seen as a directed, weighted network of trade relations between countries and countries. Any country i,j are nodes in

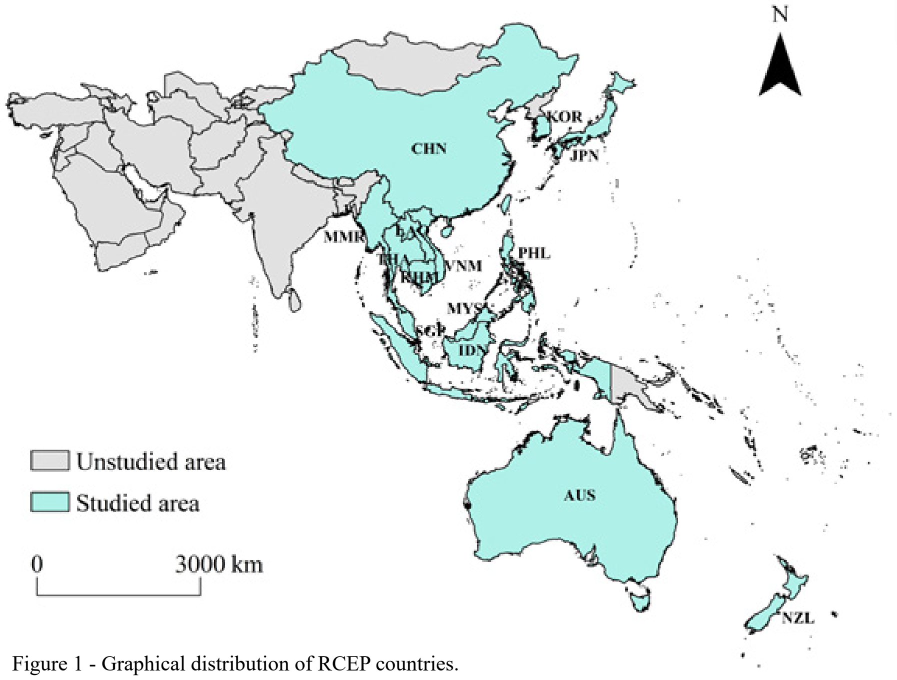

Figure 1 - Graphical distribution of RCEP countries.

the network, A_{ij} represents the directed trade relationship from node i to node j, and W_{ij} is the trade volume. This paper takes the RCEP 15 countries as the trade nodes and the export trade relations between countries as the edge, and constructs the agricultural product trade network of the RCEP15 countries according to the theory of social network, which theoretically includes 15 nodes and 210 edges.

Overall network metric

The overall network characteristics analyze the spatial network structure of all members in the network, which consists of network density, network connectedness, network hierarchy, and network efficiency (WHITE, 1976).

Network density reveals the closeness of the connection of each node member in the network by the ratio of the actual number of internal connections to the theoretical maximum possible number of connections. It is defined as follows.

$$D = \frac{L}{N(N-1)}$$

Where D is network density, N is the total number of members in the network, and L is the actual number of internal connections.

Network connectedness is used to measure the stability of the network connection, and the closer the connectedness is to 1, the more stable the network structure is. The calculation formula is as follows.

$$C = 1 - \left[\frac{V}{N(N-1)/2}\right]$$

Where C is network connectedness, and V is the number of unreachable pairs of members in the network.

Network hierarchy measures the degree of asymmetric accessibility among network members. The higher hierarchy, the more rigid the network is, indicating that only a few internal members are in a dominant position. The calculation formula is as follows.

$$H = 1 - \frac{K}{\max(K)}$$

Where H is network hierarchy, and K is the number of symmetrically reachable pairs of members in the network.

Network efficiency measures the stability of the network structure by the number of redundant connections in the network. The lower the network efficiency, the more paths to spillover outside, and the more the network structure tends to be relatively stable. Conversely, the higher the network efficiency, the fewer spillover paths, which inhibit the spatial flow and synergistic effect of agricultural trade. The calculation formula is as follows.

$$E = 1 - \frac{M}{\max(M)}$$

Where E is network efficiency, and M is the number of redundant connections in the network.

Individual network metric

Individual network characteristics are mainly reflected by degree centrality, closeness centrality, and betweenness centrality to measure the position and role of members in the network. Degree centrality is characterized by the number of an individual member's network connections to represent its position in the network. The higher the number of connections generated, the higher the degree centrality of that member, and the higher the centrality in the overall network. The calculation formula is as follows.

$$C_{AD} = \frac{n}{N-1}$$

Where CAD is degree centrality of a member, and n is the number of other members in the network that are directly connected with this member.

Closeness centrality refers to the degree of direct connection of individual members with other members within the network. A member with higher value indicates a more direct connection and more central actor status in the network, whose behavior is not controlled by other members and has independence of action. The formula is as follows.

$$C_{AC} = \sum_{j=1}^{N} d_{ij}$$

Where C_{AC} is closeness centrality, d*ij* is the distance of shortcut between two members *i* and *j*.

Betweenness centrality reflects the degree of control that individual members have over other members within the network. A higher betweenness centrality value indicates that the connection with other members is closer and the intermediation role is more obvious. The formula is as follows.

$$C_{AB} = \frac{2\sum_{j}^{N}\sum_{k}^{N} b_{jk}(i)}{N^2 - 3N + 2}$$

$$b_{jk}(i) = \frac{g_{jk}(i)}{g_{jk}}$$

Where C_{AB} is between centrality, g_{jk} is the number of shortcuts between members j, k, $g_{jk}(i)$ is the number of shortcuts between members j and k that pass through member i, $b_{jk}(i)$ is the probability that member i is on a shortcut between j and k, $j \neq k \neq i$, and $j < k$.

Block model

The block model mainly describes the location characteristics of network nodes through spatial clustering to clarify the roles and status of each member in the network structure. Referring to the existing network models evaluation methods on, the blocks in the RCEP agricultural trade spatial network are classified into four types (net spillover block, main beneficiary block, broker block, and two-way spillover block) in this study, and the connection characteristics within and between blocks are also been analyzed in depth.

QAP regression

The QAP (Quadratic Assignment Procedure) method is a non-parametric method used to quantitatively measure the correlation coefficient and regression relationship between a single dependent variable matrix and multiple independent variable matrices (BAYAT & SEDGHI, 2009). Specifically, it has the following three steps: (1) regularized multiple regression analysis of the corresponding longitudinal elements of the independent variable matrix and the dependent variable matrix; (2) randomly replacing each row and column of the dependent variable matrix and re-estimating the regression coefficient to determine the regression equation; (3) calculating the proportion of random permutations that are greater than or equal to the actual parameter estimates in all random permutations, thus estimating the standard error of the statistic and completing the significance test. The QAP regression method is adopt-ed to analyze the influencing factors of the formation of the RCEP agricultural trade spatial network structure in this study.

Data sources

The sum of imports and exports of agricultural trade in RCEP countries is selected to construct a relational network database from 2002 to 2020. The data is from the UN COMTRADE (https://comtrade.un.org/data/). The standard of data is Food and Beverage in the BEC code. In the bilateral data that uses the secondary assignment procedure method to explore the analysis of influencing factors, economic-social conditions and resource endowment data come from the World Bank World Development Index database (https://databank.worldbank.org/reports.aspx?source=world-development-indicators). Language proximity index and geographic distance data come from the French CEPII database (https://www.cepii.fr/CEPII/fr/bdd_modele/bdd_modele.Asp). The political governance environment indicators come from the World Bank World Political Governance Indicators Database (https://databank.worldbank.org /data /reports. aspx? source = worldwide-governance-indicators #dbMetadata).

RESULTS

Structural characteristics of agricultural trade spatial network

Overall network characteristics

Since the transmission direction and key nodes of the spatial association network of agricultural trade in RCEP countries did not change significantly during the sample period, the association network diagram of agricultural trade in RCEP countries in 2020 is drawn as illustration. As shown in figure 2, it can be found that RCEP agricultural trade shows a more obvious network structure, with significant differences in the relationships among nodes. China, Australia, Thailand, Vietnam, Japan, and Indonesia have significantly higher correlation strengths.

Figure 3 displays overall network structure and evolution of the density value of the agricultural trade association network at two-year intervals from 2002 to 2020 in RCEP countries. The overall change trend, for both the network density and the number of network connections, shows an M-shaped characteristic of “rising-falling-rising-falling”. The network density increased from 0.295 in 2002 to 0.352 in 2006, and the number of network connections also increased from 62 in 2002 to 74 in 2006, indicating an overall increase of connections among RCEP countries in agricultural trade during this period. It is notable that both the number of network connections and network density decreased from 2006 to 2010 and reached low values in 2010, at 66 and 0.314, respectively. This is mainly due to the lagged impact of food embargoes, food export controls, and high volatility in food prices triggered by the global food crisis in 2008, which harms the spatial network structure of agricultural trade in RCEP countries. Since then, with the stabilization of global food prices and economic recovery, agricultural trade among RCEP countries has gradually rebounded, the network density and the number of connections have slightly increased from 2010 to 2014. However, from 2014 to 2020, the network density and the number of network connections of RCEP agricultural trade experienced a dramatical decline. In 2020, the network density and the number of connections were only 0.295 and 62, reaching the lowest value in the past 20 years. This is mainly due to the gradual rising of international trade protectionism, combined with the outbreak and spread of the COVID-19, and the further intensification of the trend of economic nationalism, which have caused the inter-regional countries to fall into temporary dilemma in agricultural trade cooperation. In general, the maximum value of the overall network density is only 0.376 and the number of connections is only 79, while the maximum possible total number of connections among all countries is 210 and the maximum possible network density value is 1, indicating that RCEP countries have a low level of agricultural trade. Hence, there is still much room for development in agricultural exchanges and cooperation.

The overall structural characteristics of the agricultural trade association network in RCEP countries is further analyzed by network connectedness, network hierarchy, and network efficiency indicators. The network connectedness of

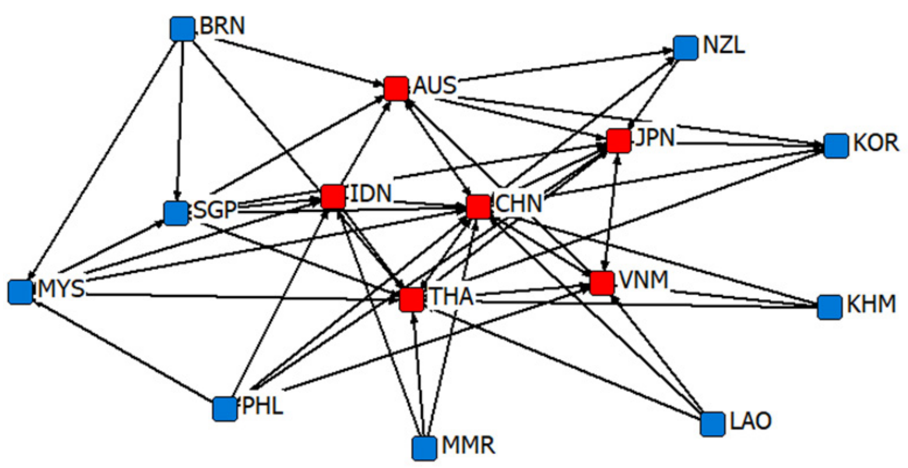

Figure 2 - Spatial association network of agricultural trade in RCEP countries in 2020.

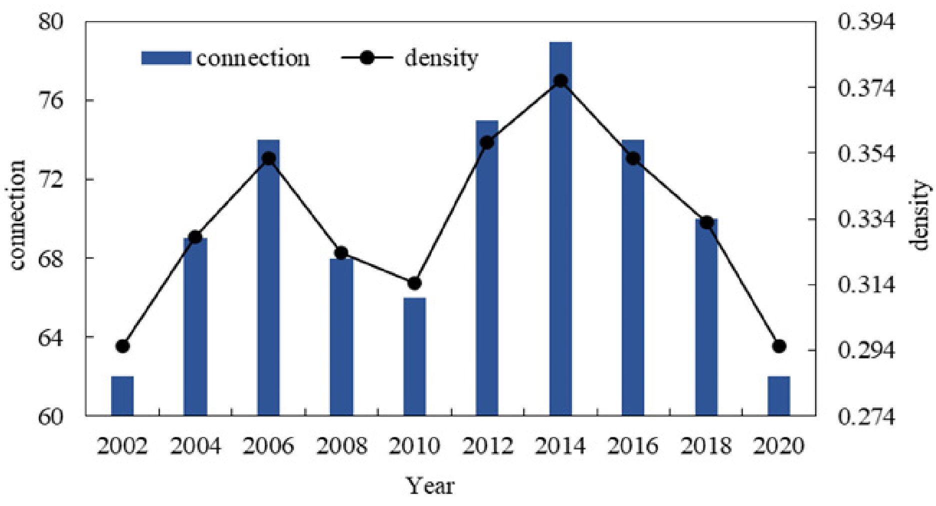

Figure 3 - Density and connection number of the spatial network of agricultural trade in RCEP countries.

agricultural trade from 2002 to 2020 is 1, indicating that there are obvious spatial connections in agricultural trade among countries and the network is well connected. The network hierarchy and network efficiency show a W-shaped characteristic of "falling-rising-falling-rising" (Figure 4). Network hierarchy decreased from 0.604 in 2002 to 0.526 in 2020. Especially under the influence of the 2008 financial crisis, the network hierarchy continued to decline, reflecting that the relatively strict spatial network structure may be further broken, and the agricultural trade network of RCEP countries will show a balanced development trend. Additionally, the network efficiency also declined from 0.604 in 2002 to 0.582 in 2018, which implies that each node has multiple overlapping spillover channels, the network connectivity among countries is continuously strengthened, and the network stability is gradual enhanced. However, the network efficiency in 2020 increased to 0.648, which is mainly due to the impact of the sudden epidemic crisis and the slightly insufficient response capabilities of RCEP countries, and the stability of the trade network is slightly reduced.

Individual network characteristics

Three individual network characteristics indicators of degree centrality, closeness centrality, and betweenness centrality are measured to further illustrate the position and role of countries in the spatial association network of agricultural trade in each country of RCEP. We analyzed the data from 2002 to 2020, and table 1, table 2 and table 3 reports the value of three indicators in 2002, 2008, 2014 and 2020, respectively. According to the measurement results, figure 5 shows the distribution of spatial association individuals' network characteristics in each country in 2020.

Degree centrality

According to the degree centrality results, in 2002, 2008, 2014 and 2020, the degree centrality were 47.619, 50.476, 53.333 and 43.810 respectively, and the degree centrality showed a downward trend as a whole, and the spatial distribution was obviously uneven, but the changes between the high and low value areas were not obvious (Table 1). Among them, whether in 2002, 2008, 2014 or 2020, the degree centrality of Australia, China, Indonesia, Japan, Singapore, Thailand and Vietnam is higher than the average. The reason is, China, Japan, and Singapore are typical grain importers. Due to insufficient domestic food demand, the above countries urgently need external markets to meet the food supply. Australia, Thailand, and Vietnam are typical grain exporters, exporting grain to obtain foreign exchange or for financial profit. The stability of the overall network structure is highly dependent on the above importing countries.

Since during the study period 2002-2020, the change in degree centrality is not significant. Therefore, in this section, we only used data from 2020 to analyze individual results for degree centrality, point out, and point in. In RCEP countries, China has

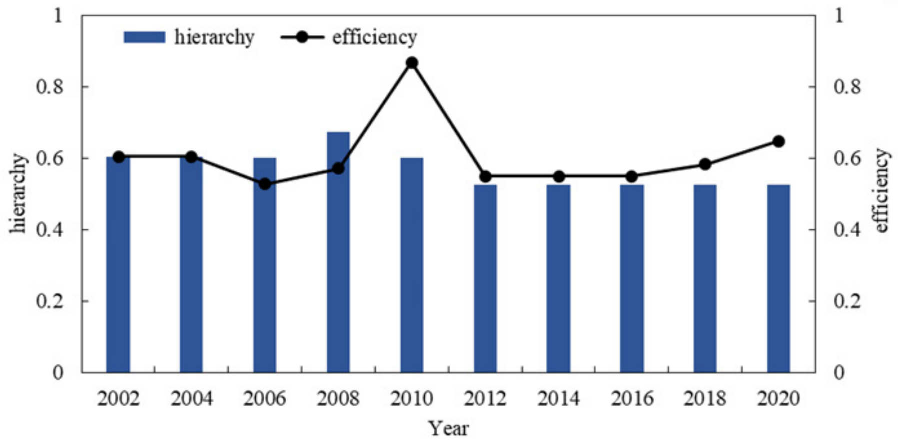

Figure 4 - Hierarchy and efficiency of the spatial network of agricultural trade in RCEP countries.

the highest degree centrality (92.857), indicating that it is at the core of the spatial network structure. The reason is that China has obvious spatial connections with eight of the other fourteen RCEP countries. However, Brunei, Laos, and Myanmar rank relatively lower, and these countries are less connected to other countries and have a subordinate position in the spatial network structure. The plausible reasons are related to the slow level of economic development and the relatively weak scale of agricultural trade in these countries.

Furthermore, as shown in figure 6, the average point out-degree and point in-degree of centrality are both 4.133. There are seven countries with point in-degree greater than the average (Australia, China, Indonesia, Japan, Malaysia, Thailand, and Vietnam), which are mostly the main areas for agricultural trade. Seven countries (Australia,

Table 1 - Analysis of degree centrality of the spatial network of agricultural trade in various countries from 2002 to 2020.

Country	Degree centrality							
	2002		2008		2014		2020	
	degree	rank	degree	rank	degree	rank	degree	rank
AUS	78.571	1	71.429	3	71.429	3	57.143	3
BRN	28.571	11	28.571	11	28.571	12	28.571	10
CHN	71.429	3	85.741	1	92.857	1	92.857	1
IDN	50.000	7	50.000	7	50.000	9	50.000	5
JPN	71.429	3	71.429	3	57.143	7	57.143	3
KHM	14.286	15	35.714	10	35.714	10	21.429	12
KOR	28.571	11	28.571	11	28.571	12	28.571	10
LAO	21.429	14	14.286	15	21.429	15	21.429	12
MMR	35.714	9	42.857	9	35.714	10	21.429	12
MYS	64.286	5	71.429	3	71.429	3	42.857	8
NZL	28.571	11	28.571	11	28.571	12	21.429	12
PHL	35.714	9	28.571	11	57.143	7	35.714	9
SGP	64.286	5	64.286	6	78.571	2	50.000	5
THA	78.571	1	85.741	1	71.429	3	78.571	2
VNM	42.857	8	50.000	7	71.429	3	50.000	5
Mean	47.619	—	50.476	—	53.333	—	43.810	—

Table 2 - Analysis of closeness centrality of the spatial network of agricultural trade in various countries from 2002 to 2020.

Country	Closeness centrality							
	2002		2008		2014		2020	
	degree	rank	degree	rank	degree	rank	degree	rank
AUS	82.353	1	77.778	3	77.778	3	70.000	3
BRN	58.333	11	58.333	11	58.333	12	58.333	10
CHN	77.778	3	85.500	1	93.333	1	93.333	1
IDN	66.667	7	66.667	7	66.667	9	66.667	5
JPN	77.778	3	73.778	3	70.000	7	70.000	3
KHM	50.000	15	60.870	10	60.870	10	56.000	12
KOR	56.000	12	58.333	11	58.333	12	58.333	10
LAO	53.846	14	51.852	15	56.000	15	56.000	12
MMR	60.870	8	63.636	9	60.870	10	56.000	12
MYS	73.684	5	77.778	3	77.778	3	63.636	8
NZL	56.000	12	56.000	14	58.333	12	56.000	12
PHL	60.870	8	58.333	11	70.000	7	60.870	9
SGP	73.684	5	73.684	6	82.353	2	66.667	5
THA	82.353	1	87.500	1	77.778	3	82.353	2
VNM	60.870	8	66.667	7	77.778	3	66.667	5
Mean	66.072	—	68.181	—	69.747	—	65.391	—

China, Indonesia, Japan, Malaysia, Thailand, and Vietnam) have greater point in-degree than point out-degree, reflecting that the above countries benefit from the spatial network structure to a much greater extent than the spillover. The point in-degree of the Brunei, Cambodia, Laos, Myanmar, and Philippines is much smaller than the point out-degree, indicating that they cause a significant spillover effect in the correlation network. Overall, the point in-degree is larger than point out-degree for countries with larger degree centrality. For example, China ranks first in degree centrality, with a significantly larger point in-degree (13) than point out-degree (8), indicating that it is both a beneficiary and an important spillover in the network, and occupies a central position in the spatial network of agricultural trade.

Closeness centrality

The mean values of near centrality in 2002, 2008, 2014 and 2020 are 66.072, 68.181, 69.747 and 65.391, respectively, and the difference between the beginning and end of the period is only 0.681, indicating that the distribution of near centrality is relatively stable in the study period from 2002 to 2020. In 2002, 2008, 2014 and 2020, seven countries are close to centrality above the mean in seven countries: Australia, China, Indonesia, Japan, Singapore, Thailand, and Vietnam (Table 2). They also have a high degree centrality, which reflects the central status of these countries in the spatial network and maintains close ties with other countries. The results of the 2020 measurement are used as an example for analysis. The closeness centrality of China is 93.333. It is significantly higher than other countries, indicating that China is at the center of the network and is relatively “close” to the other RCEP countries. Countries such as Cambodia, Laos, Myanmar, and New Zealand rank lower in closeness centrality, and locate at the periphery of the RCEP spatial network of agricultural trade.

Betweenness centrality

In 2002, 2008, 2014 and 2020, the average intermediary centrality of agricultural trade networks in RCEP countries are 3.867, 3.533, 3.590 and 4.322, respectively, with a slight increase, indicating that the intermediary function of network nodes has an increasing trend (Table 3). However, the difference between the beginning and end of the period is only 0.455, which also indicates that the evolution of intermediary centrality is relatively stable during the study period. In both 2002 and 2020, Australia, China, Thailand and Vietnam all had higher than average intermediary centrality, and their intermediary role in

Table 3 - Analysis of between centrality of the spatial network of agricultural trade in various countries from 2002 to 2020.

Country	-----Between centrality-----							
	----2002----		----2008----		----2014----		----2020----	
	degree	rank	degree	rank	degree	rank	degree	rank
AUS	10.693	2	6.375	5	7.454	3	6.447	3
BRN	0.000	13	0.000	14	0.143	10	0.432	10
CHN	6.093	5	9.335	2	16.677	1	24.040	1
IDN	1.126	8	0.292	9	0.810	9	3.032	6
JPN	7.542	4	6.260	3	2.467	7	4.498	4
KHM	0.000	13	0.343	8	0.000	11	0.000	12
KOR	0.000	13	0.000	14	0.000	11	0.157	11
LAO	0.525	10	0.143	10	0.000	11	0.000	12
MMR	0.143	12	0.125	12	0.000	11	0.000	12
MYS	8.397	3	6.043	4	4.369	6	2.143	7
NZL	0.393	11	0.125	12	0.000	11	0.000	12
PHL	0.611	9	0.143	10	1.700	8	1.136	9
SGP	4.876	6	2.742	7	5.780	5	1.842	8
THA	14.796	1	16.658	1	7.637	2	17.161	2
VNM	2.808	7	4.992	6	6.293	4	3.948	5
Mean	3.867	—	3.533	—	3.590	—	4.322	—

the network is also very obvious. Based on the above analysis, this article uses the results of the 2020 study to illustrate the details. Four countries (Australia, China, Thailand, and Vietnam) are above the average, namely Australia, China, Thailand, and Vietnam, which are important in the network and have some control over the agricultural trade of other countries. The sum of betweenness centrality of these four countries is 52.146, accounting for more than 80% of the total betweenness centrality. Most of the aforementioned countries have relatively better economic levels and play a stronger role as intermediaries and bridges in the trade network, which are more likely to absorb the inflow of trade resources from other countries. However, Laos, Myanmar, New Zealand, and other countries rank low in the betweenness centrality. The sum of betweenness centrality of the bot-tom-ranked countries is only 12.690, which makes it difficult for them to play a pivotal role in the entire agricultural trade network.

Through the analysis of the previous results, we concluded that the individual network characteristics of agricultural trade in RCEP countries are relatively stable. This is mainly due to the fact that the agricultural trade network of the RCEP15 countries has formed a clear core-periphery structure, and the changes in its existence are also concentrated within the clusters. Among them, China, Australia, Japan, Thailand, Vietnam and other countries have a large trade scale and close trade ties with the countries in the group, which is a relatively important trade node. The fringe area presents a "three-core, multi-node" structure, with Malaysia, the Philippines and Singapore as the core areas, and Brunei, Cambodia, Laos, Myanmar and New Zealand as the sub-node areas. On the whole, the proportion of sub-node areas in the periphery is relatively large, and the trade links between these countries and the countries inside and outside the cluster are weak and need to be strengthened, so it also leads to the lower ranking of the centrality index of these countries. This result also suggested that we should introduce differentiated agricultural trade policies according to local conditions in view of the different positions of countries in the overall association network and internal group network, so as to give full play to the main role of different countries in regional trade.

Block model analysis

The spatial correlation network of agricultural trade in RCEP countries is analyzed using the block model analysis method and is divided into four blocks. Then, the spatial correlation characteristics and the action patterns

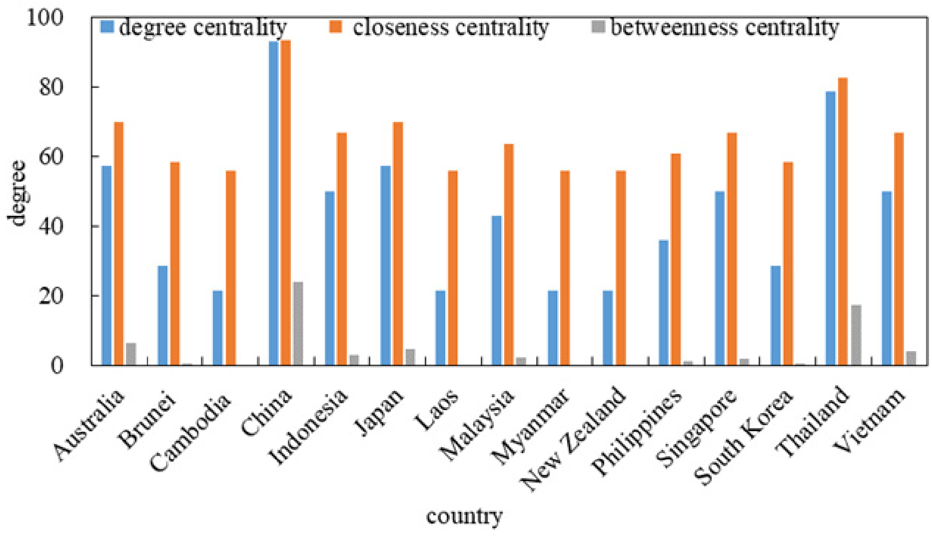

Figure 5 - Spatial association individual network of RCEP countries.

within and across the blocks are further analyzed (Table 4 and Figure 7).

The results showed that the block I includes three countries, Australia, China, and Thailand. The number of ex-ternal block relationships received by block I is 28, which is significantly higher than the number of relationships outside the spillover block of 11. The actual internal relationships ratio of 26.667% is also significantly higher than the expected internal relationships ratio of 14.286%, which implies that the net spillover effect in block I is very limited, and it is the "net benefit block". Economies located in this sector have a relatively weak competitive advantage in agricultural trade in the international market, and mainly rely on imports of agricultural trade outside the sector to meet the needs of member countries. The block II includes Japan, New Zealand, Vietnam, and South Korea. It has 15 spillover relationships, four internal relationships, and 11 spillover relationships to other

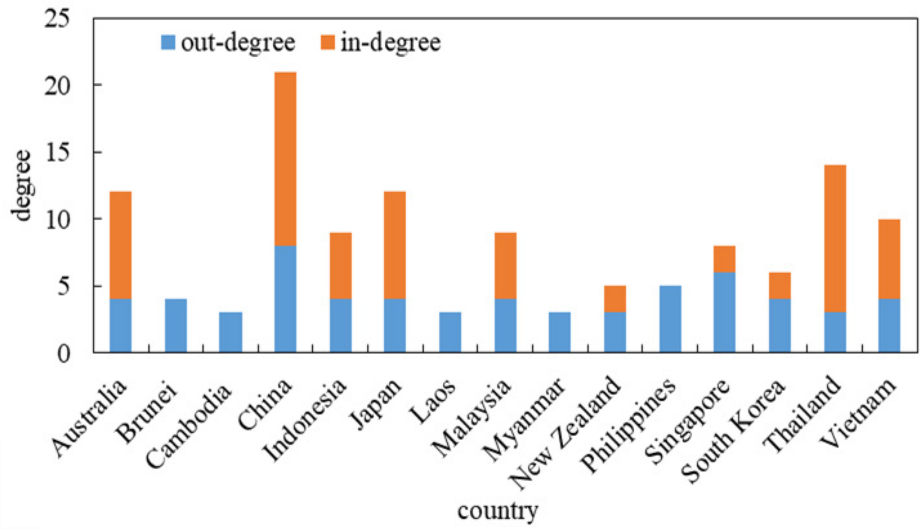

Figure 6 - Out-degree and in-degree of countries.

Table 4 - Analysis of the spillover effects of each block of the RCEP agricultural trade spatial network in 2020.

Block	Number of receiving relationships				Number of members	Receiving the number of external relationships	Number of spillover relationships	Expected proportion of internal relationship (%)	Actual internal relationship ratio (%)	Block characteristics
	I	II	III	IV						
I	4	9	2	0	3	28	11	14.286	26.667	Net benefit
II	11	4	0	0	4	14	11	21.429	26.667	Broker
III	10	1	7	0	4	5	11	21.429	38.889	Two-way spillover
IV	7	4	3	0	4	0	14	21.429	0.000	Net spillover

blocks. It receives 14 external relationships, and the difference between the expected internal ratio and the actual internal ratio is smallest. Economies located in this sector can not only undertake agricultural trade from hot spots, but also drive and radiate the development of agricultural trade in other sectors, and have the role of "connecting the top and the bottom" and is the "broker block". The block III includes Brunei, Indonesia, Malaysia, and Singapore with 18 spillover relationships, seven internal relationships, 11 spillover relationships to other blocks, and five spillover relations from other blocks, and has the relatively small gap between the expected ratio of internal relationships and the actual ratio of internal relationships. That is, the block not only receives spillovers from other blocks, but also has spillover effects on other blocks, and has more spillovers to other blocks. Hence, it is a "two-way spillover block" with the function of "connecting the above and the below". The economies located in this sector have a similar number of agricultural trade and export relations and a very small number of intra-plate trade relations, and these economies play a "bridge" role in the network of agricultural trade relations. The block IV includes four countries, namely Cambodia, Laos, Myanmar, and Philippines. The actual internal relationship ratio of this block is zero, and the number of spillover relationships from this block to other blocks is 14, while the number of spillover relationships received from other blocks

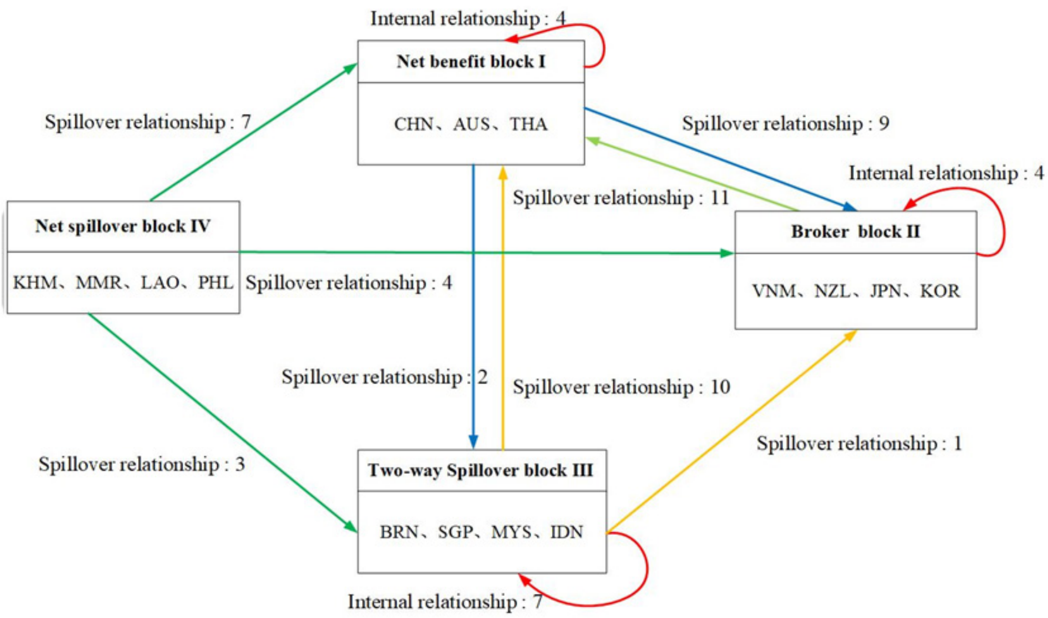

Figure 7 - The transfer relationship between the four major blocks of the RCEP agricultural trade spatial network.

is only zero. The number of spillover relationships to other blocks is much higher than the number of relationships outside the receiving block, which is the "net spillover block". Economies located in this sector have significantly greater agricultural trade export relationships than other sectors, indicating strong export capacity in international markets.

The agricultural trade correlations and spillover relationships among the blocks are further examined by calculating the network density matrix. If the block density is less than the overall network density, it indicates that the agricultural trade shows a discrete trend, so it is reassigned to zero, otherwise one. Then, the density matrix is con-verted into an image matrix (Table 5).

According to the image matrix, the correlation diagram can be drawn to visualize the correlations and transmission mechanisms that exist between agricultural trade blocks (Figure 7). The elements on the diagonal of the image matrix are all 1 except for block IV, indicating that the agricultural trade network is essentially significantly correlated within each block.

Specifically, from the inside of the block, except block IV, the rest of the blocks are significantly related to their own, and the club agglomeration effect is good. From the outside of the block, Block I mainly accepts the spillover relationships from Block II, Block III, and Block IV. Block II mainly accepts the spillover relationships from Block I. In contrast, Block III and Block IV are less connected to other blocks and exhibit isolated features.

Structural characteristics of agricultural trade spatial network

Indicators selection

The spatial network structure of agricultural trade in RCEP countries is influenced by a combination of factors. In this paper, the factors influencing the formation of agricultural trade network structure are selected from geographical distance, economic and social conditions, resource endowment, language proximity index, and political governance environment. Then, the network matrix of influencing factors is constructed (Table 6).

Geographical distance

Agricultural trade is an important component of international trade in goods, and geographical distance (*DIST*) has a significant impact on the transportation costs of agricultural products. The closer the distance, the smaller the transaction cost, and the greater the possibility that both parties will trade.

Economic and social conditions

Economic and social conditions include Gross Domestic Product (*GDP*), total population (*POP*), and trade openness (*OPEN*). *GDP* is an important indicator of each country's or region's ability to satisfy import demand. The classical trade gravity model assumes that the larger the size of a country's economy, the stronger the potential demand for agricultural products. The difference in total economic size between two countries is also an important factor affecting agricultural trade relations. The larger the population of a country, the greater the demand for agricultural products (BALL & LINNERMANN, 1967), and the more likely it is to trade in agricultural products. However, it is also possible that when the population size increases, the domestic production capacity is relatively developed and the dependence on international markets gradually decreases, which may inhibit the development of agricultural trade. *OPEN* is characterized by *FDI* net inflow as a proportion of *GDP*. It reflects the degree of openness and market dependence of a country. The difference in the level of trade openness directly affects the consumer demand of importing countries, which in turn affects the agricultural trade between the two countries.

Table 5 - Density matrix and image matrix of each block of the RCEP agricultural trade spatial network in 2020.

Block	-------------------------------Density matrix-----------------------------------				-----------------Image matrix----------------			
	I	II	III	IV	I	II	IIII	IV
I	0.667	0.750	0.167	0.000	1	1	0	0
II	0.917	0.333	0.000	0.000	1	1	0	0
III	0.833	0.063	0.583	0.133	1	0	1	0
IV	0.583	0.250	0.188	0.000	1	0	0	0

Table 6 - Indicators and descriptions.

Indicator	Specific meaning	Calculation method and description
DIST	Capital distance between countries	Geographical distance network of capitals between countries
GDP	Gross Domestic Product	Network of differences in the level of economic development between countries
POP	Total population	Inter-country population gap network
OPEN	FDI net inflow as a proportion of GDP	Difference network of net foreign direct investment inflows between countries
LAND	Arable land per capita	Network of differences in per capita cultivated land between countries
LANG	Language proximity index	The common language used between countries is 1, otherwise 0
PSI	Political stability index	Inter- country political stability index difference network
GEI	Government effectiveness index	Inter-country government effectiveness index difference network

Resource endowment

The arable land per capita (*LAND*) provides a more accurate picture of arable land re-sources that a country possesses. The scarcity of resources directly affects the amount of supply and demand for a country's agricultural trade, and thus the likelihood that it will occur.

Language proximity index

The use of a common official language (*LANG*) also affects the smooth conduct of agricultural trade. Language and culture positively contribute to the agricultural trade with their common national ties and values and affect the persistence and stability of agricultural trade. This paper uses the language proximity index to measure it.

Political governance environment

It includes political stability index (*PSI*) and government effectiveness index (*GEI*). The higher the political stability of a country, the higher the likelihood of agricultural trade occurring. *GEI* is measured in terms of government governance, policy-making compliance, and policy implementation quality. To a certain extent, it reflects the public's perception on the quality of government personnel and the performance of government governance. The level of government effectiveness index also affects the development of agricultural trade (AMSTRONG, 2007).

Therefore, geographical distance (*DIST*), *GDP* structure difference (*GDP*), total population difference (*POP*), trade opening difference (*OPEN*), the arable land per capita difference (*LAND*), language proximity index (*LANU*), political stability index (*PSI*), and government effectiveness index (*GEI*) are selected to describe the driving factors of RCEP countries' agriculture trade spatial association network. And the model is established as:

$$F = f\,(a_1DIST,\ a_2GDP,\ a_3POP,\ a_4OPEN,\ a_5LAND,\ a_6LANG,\ a_7PSI,\ a_8GEI$$

Where F is the agricultural trade network matrix, *DIST*, *GDP*,..., and *GEI* are the influence factor of relation-ship matrices, respectively, and a_1 to a_8 are the coefficients.

Regression analysis based on QAP method

The regression results (Table 7) showed that the RCEP agricultural trade network model from 2002-2020 has generally passed the significance test, and the drivers have good explanatory power on the structure of agricultural trade network. The R^2 values of the QAP regression models basically maintains the upward trend with slight fluctuations, and the regression models gradually tend to be robust. As time evolves, the degree and direction of the influence of different driving factors on the spatial network structure changes, showing an obvious differentiation characteristic. The detailed explanation is as follows.

Geographical distance has a negative effect on the RCEP agricultural trade network. From 2002-2016, the geographical distance network continuously passes the significance test with coefficient values largely in the range of -0.18 to -0.26 and highly stable in the -0.22 to -0.25 interval. And the geographic distance also passes the 1% statis-tical significance test with a coefficient of -0.264 in 2020. This indicates that the more distant the two capitals are, the weaker the correlation of agricultural trade is. It is mainly affected by the short shelf life, large volume, and corrosiveness of the agricultural products themselves, as well as the increased transportation costs.

Economic and social conditions have the greatest impact on the RCEP agricultural trade network. The *GDP* difference network has the significantly positive affect on the formation of the

Table 7 - QAP regression results of RCEP agricultural trade network.

Variable	2002	2004	2006	2008	2010	2012	2014	2016	2018	2020
DIST	-0.260^{***}	-0.250^{***}	-0.215^{***}	-0.255^{***}	-0.185^{**}	-0.226^{***}	-0.259^{***}	-0.221^{***}	0.127	-0.264^{***}
	(1.000)	(0.995)	(0.995)	(0.997)	(0.977)	(0.994)	(0.995)	(0.997)	(0.464)	(1.000)
GDP	0.298^{***}	0.311^{***}	0.286^{***}	0.255^{**}	0.178^{**}	0.160^{*}	0.162^{*}	0.175^{**}	0.115^{*}	0.209^{**}
	(0.002)	(0.001)	(0.003)	(0.009)	(0.029)	(0.062)	(0.067)	(0.046)	(0.101)	(0.018)
POP	0.074	0.05	0.083	0.075	0.155^{**}	0.211^{**}	0.224^{**}	0.226^{**}	0.127	0.189^{**}
	(0.186)	(0.298)	(0.192)	(0.242)	(0.059)	(0.016)	(0.021)	(0.008)	(0.482)	(0.038)
OPEN	0.054	0.09	0.005	-0.047	-0.026	-0.137^{*}	-0.048	-0.087	-0.046	-0.135^{*}
	(0.208)	(0.133)	(0.508)	(0.727)	(0.649)	(0.939)	(0.678)	(0.854)	(0.695)	(0.938)
LAND	0.111	0.069	0.150^{**}	0.165^{**}	0.196^{**}	0.175^{**}	0.153^{*}	0.179^{*}	0.128^{*}	0.149^{**}
	(0.115)	(0.244)	(0.030)	(0.038)	(0.027)	(0.057)	(0.068)	(0.031)	(0.090)	(0.042)
LAGU	0.179^{**}	0.124^{*}	0.176^{**}	0.094	0.166^{**}	0.162^{**}	0.145^{**}	0.116^{*}	0.123^{**}	0.132^{**}
	(0.006)	(0.056)	(0.015)	(0.112)	(0.020)	(0.024)	(0.048)	(0.064)	(0.049)	(0.042)
PSI	-0.083	-0.017	0.055	-0.015	0.045	-0.084	0.036	-0.053	-0.062	-0.052
	(0.862)	(0.627)	(0.235)	(0.582)	(0.286)	(0.891)	(0.325)	(0.766)	(0.801)	(0.762)
GEI	-0.009	-0.002	-0.101^{**}	-0.121^{*}	-0.158^{**}	-0.015	-0.09	-0.114^{*}	-0.202^{***}	-0.197^{***}
	(0.555)	(0.535)	(0.925)	(0.925)	(0.972)	(0.582)	(0.852)	(0.937)	(0.996)	(0.992)
R^2	0.158	0.135	0.141	0.123	0.136	0.191	0.164	0.18	0.194	0.247
Adi-R^2	0.129	0.105	0.111	0.093	0.106	0.163	0.135	0.152	0.166	0.221
P value	0.000	0.000	0.000	0.000	0.000	0.0000	0.000	0.000	0.000	0.000
Observation	210	210	210	210	210	210	210	210	210	210

Note: The coefficients of the variables in the table are standardized regression coefficients; *, **, *** indicate significant at the levels of 10%, 5%, and 1% respectively. The value in brackets indicates the probability that the regression coefficient generated by random replacement is not less than actually observed regression coefficient.

RCEP agricultural trade network structure in all ten years. The larger the difference in *GDP* between the two countries, the greater the possibility of agricultural trade. It is noteworthy that the coefficient value shows a decreasing trend in general, more obvious during 2008-2012, which is mainly due to the lag effect caused by the global financial crisis. The total population difference also has a positive impact on the agricultural trade network, indicating that the greater the population difference between the two countries, the more likely it is to establish agricultural trade relations. However, it only passes the significance test in the five years of 2010, 2012, 2014, 2016 and 2020, and the coefficient values show an up-ward trend as a whole. This may be related to the "driving hypothesis" proposed by Alesina. The expansion of the importing country's population increases their domestic agriculture production and consumption capacity, which may discourage agricultural imports, making the positive effect of the total population difference on agricultural trade insignificant. The difference in net *FDI* inflows as a percentage of *GDP* on agricultural trade net-work only passes the significance test in 2020. It may reflect that this indicator has not yet become a major factor affecting the RCEP agricultural trade network.

Resource endowment positively affects the RCEP agricultural trade network. The difference in arable land area per capita from 2002 to 2020 pass the significance test with an upward trend in the whole, which further reflects the dependence of agricultural trade development on resource endowment. Specifically, the regression results for 2020 pass the 5% statistical significance test with a contribution of 14.90%, indicating that the greater the difference in arable land area per capita between the two countries, the more favorable the occurrence of agricultural trade.

Language proximity index has a significantly positive effect on agricultural trade network from 2002-2020 with coefficient values largely ranging from 0.15 to 0.18. It suggests that countries using the same language are more likely to have trade correlations. In fact, Chinese-speaking countries such as China, Malaysia, Singapore, and English-speaking countries such as Australia, New Zealand, Philippines, and Singapore have maintained close agricultural trade relations for a long time, which may be related to the cultural foundation and value orientation endowed by the common language.

The political governance environment on agricultural trade network is generally insignificant, and the coefficient values of the two indicators also show fluctuating changes. The *PSI* fails to pass the significance test, which may be related to the continuous improvement of agricultural trade rules of WTO, ASEAN, and other relevant international organizations. In this context, the influence of a country's political stability on the agricultural trade network is gradually weakened. The *GEI* only passes the significance test in the six years and shows a negative im-pact. It is generally believed that the similar management characteristics between the two countries are conducive to the business development and moderate reduction of investment resistance. However, the model results showed that government governance efficiency has a negative impact on the agricultural trade network, but its significance is fluctuating, and the negative impact is not strictly significant.

DISCUSSION

In this study, the agricultural trade network of RCEP countries is constructed using agricultural trade data from 2002 to 2020. The structural characteristics of association networks are analyzed by adopting social network methods. Further, the QAP method is used to quantitatively evaluate the factors influencing the formation of the net-works.

As an overall view, the agriculture trade's correlation relationships in RCEP countries show complex network structure characteristics. The network density is only 0.295 currently, and the spatial correlation network has good accessibility. The network hierarchy and efficiency show an integral fluctuating decline, with the strict network hierarchy being broken gradually and the network stability being improved in an orderly manner. In terms of the in-dividual network structure, the position of each country in the association network has obvious heterogeneity. Countries with China as the core are in the leading position of the central actor, while countries such as Cambodia, Laos, and Myanmar are in the position of peripheral actors. From the core-periphery structure and block model analysis, the spatial association network shows that the core area is expanding and the peripheral area is shrinking, with the core area mainly distributed in East Asia and the Malay Archipelago, and the peripheral area mainly distributed in the Indo-China Peninsula. Meanwhile, the spatial association network of agricultural trade can be divided into four blocks. Australia, China, Vietnam, and Thailand belong to the net beneficial block, while Cambodia, Laos, and Myanmar, are in the net spillover block.

Geographical distance, economic and social conditions, resource endowment, and language proximity index networks cause significant effects on agricultural trade networks in RCEP countries. Among them, economic and social conditions have the highest level of influence. The geographical distance, per capita arable land resource difference network, and language proximity index are negatively, positively, and positively related to agricultural trade network connections, respectively, while the political governance has no apparent significant effect on agricultural trade network.

Based on the findings, the following discussions are proposed. Firstly, the spatial network pattern of agricultural trade has changed profoundly in RCEP countries, which requires that the spatial connections in regions should be considered when formulating relevant trade policies. It is necessary to actively complete the preparations for the implementation of RCEP, increase investment support in tariff reduction, implementation of rules of origin, implementation of binding obligations of the agreement, and establishment of a free trade area implementation service platform, actively integrate into the integration of the regional economy, and at the same time conform to the trend of increasing agricultural trade ties between RCEP countries, strengthen the multilateral cooperation mechanism among RCEP member countries, and achieve complementary and mutually beneficial trade in international agricultural resources. Secondly, according to the different positions of countries in the association network, more precise and differentiated agricultural trade policies should be formulated to play the roles of different countries in the region. Countries in RCEP should further enhance their trade power, strengthen trade cooperation and policy coordination, and improve their ability to withstand pressure in the trade system according to their own characteristics. We should pay attention to the national heterogeneity of agricultural export trade of RCEP member countries, and implement country-specific management of agricultural product trade.

Formulate differentiated response strategies for different factors affecting agricultural trade among RCEP member countries, and adhere to the principle of one country, one policy, and flexibly select trade measures according to the characteristics of different countries. Thirdly, the potential cooperation between complementary blocks should be used to properly handle the competitive relations in agricultural trade. Above all, priority should be given to strengthening agricultural trade policies interaction among core countries such as China, Thailand, and Australia. Furthermore, the core country's cohesive role in the complementary network of agricultural trade is utilized to promote joint improvement of agricultural trade connections with other countries. For example, China and other countries should give full play to the role of the core position in the agricultural trade network, actively build an agricultural trade platform for RCEP countries, further promote countries to break down tariff and investment barriers between contracting countries, and create good conditions for international trade in agricultural products. Finally, the important impact of factors such as the level of socioeconomic conditions, geographical distance, and resource endowment should be fully considered. Strengthening the agricultural trade flows among neighboring countries can create new transmission channels for agricultural trade between high-level countries and low-level countries in the region. In addition, the current context of escalating trade conflicts and intensifying trade frictions, the important impacts of host country government governance and institutional risks on agricultural trade cannot be ignored. Specifically, the impact of trade distance between countries and WTO accession on agricultural export trade of RCEP member countries should be used to strengthen agricultural trade in WTO countries and countries with small geographical distances; At the same time, it is also necessary to strengthen people-to-people exchanges among RCEP member countries, strictly promote the construction of the "five links" proposed by the "Belt and Road" initiative, increase the frequency of bilateral or multilateral official and non-governmental exchanges, and eliminate the negative impact of national systems and democratic political factors on the agricultural trade of RCEP member countries.

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DECLARATION OF CONFLICT OF INTERESTS

The authors declare no conflict of interest.

AUTHORS' CONTRIBUTIONS

All authors contributed equally for the conception and writing of the manuscript. All authors critically revised the manuscript and approved of the final version.

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