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Research on the Multilayer Network of Relations of Western Agricultural Trade along the Belt and Road

Fengjie Xie, Xiaoxiao Yin and Ruifen Sun *

School of Modern Posts, Xi'an University of Posts and Telecommunications, Xi'an 710061, China
* Correspondence: sunruifen@xupt.edu.cn

Abstract: This paper defines the weighted super adjacency matrix based on the existing super adjacency matrix. This paper, for the first time, combines the trade network, competitive network, and complementary network to construct the trade multilayer network, and innovatively defines the interlayer connections. Based on this, we build trade multilayer networks for three major agricultural products in the western region along the "Belt and Road". The paper then proposes analytical methods, including a classification algorithm for local network relations and a comparative analysis of trade development priorities based on the local network relations. The former is used to identify and categorize key trading countries and potential trading countries for western agricultural products along the "Belt and Road". The latter is used to examine the western regions' order of priority in developing trade relations with the classified countries. According to the findings, category I agricultural trade has 37 key trading countries among the "Belt and Road" countries. Their local network relationships are classified into six groups, and their trade development priorities are classified into four levels. There are 49 key trading countries in category II agricultural trade. Their local network relations can be classified into three groups, and their trade development priorities can be classified into two levels. There are 62 key trading countries in category IV agricultural trade. Their local network relationships are classified into six groups, and their trade development priorities are classified into four levels. Furthermore, only Chile is a potential trading partner in category I agricultural trade. Finally, this paper offers policy recommendations for the development of agricultural trade along the "Belt and Road" in the western region.

Keywords: the "Belt and Road"; the Western region; agricultural trade; multilayer network of relations

MSC: 05C82

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1. Introduction

In 2013, President Xi Jinping of China proposed the "Belt and Road" cooperation initiative. After several years of development, the "Belt and Road" has become an important channel for China's foreign trade. Within this trade, international agricultural cooperation plays an important role in developing the "Belt and Road" initiative, and cooperation in agricultural trade is an important part of it [1]. According to the "Belt and Road" Agricultural Trade Development Report released by the Agricultural Trade Promotion Center of the Chinese Ministry of Agriculture and Rural Affairs, the volume and variety of agricultural trade between China and the "Belt and Road" countries have increased since the initiative's inception, but China has remained in deficit for a long time, and the scale of the deficit is increasing. Taking 2020 as an example, China's agricultural trade with the "Belt and Road" countries reached USD 64.76 billion, an increase of 56.3% compared to 2013. The trade deficit increased from USD 3.63 billion in 2013 to USD 10.16 billion in 2020. The western region is the main production area of agricultural products, such as vegetables, fruits, flowers, and cotton, in China, and agricultural trade is one of the important means of the country's economic development [2]. Compared with the eastern and central regions

of China, the western region is relatively underdeveloped in terms of agricultural products, but according to the data from the General Administration of Customs, since the "Belt and Road" initiative was implemented, the share of agricultural exports from the western region to the "Belt and Road" countries has become the largest, reaching 52.7%, followed by 33.8% for central China and 28.5% for the eastern China. This indicates that the "Belt and Road" countries are particularly important for the development of agricultural products in the western region. In addition, with the continuous development of the "Belt and Road" initiative and the further promotion of the opening up of the West, the western region has acquired unique location-derived advantages in foreign trade, such as the Asia-Europe Continental Bridge, and it faces new developmental opportunities and challenges in terms of its agricultural trade. Therefore, it is essential to clarify the agricultural trade relations between the western region of China and the "Belt and Road" countries. It would benefit the western region to broaden international agricultural trade channels, promote economic development, and, thus, reduce the agricultural trade deficit.

There have been many studies on international trade relations using different research methods. Some scholars have studied international trade relations by using the trade coefficient method. Ding and Xiao used the export product concentration index to analyze the diversity of China's agricultural exports to Central and West Asian countries [3]. Sang and Yang used the modified specialization coefficient (CS index) and consistency coefficient (CC index) to study China's trade relations with the "Belt and Road" countries [4]. Si and Zhou used the relative trade advantage index (RTA index) and the bilateral trade complementary coefficient (OBC index) to empirically study the industry trade relations between China and the "Belt and Road" countries [5]. He et al. used the revealed comparative advantage index (RCA index) and the trade complementarity index (TCI index) to identify the competitiveness and complementarity between China and the "Belt and Road" countries in the trade of major agricultural products [6]. Sun and Li used the export similarity index (ESI index) to study the competition between Chinese and Indian agricultural exports in the world market [7].

With the development of network theory, many scholars have begun to study international trade relations from the network perspective. Based on the type of network constructed, these studies can be divided into three major groups. The first group refers to the study of the network of international trade relations. Scholars used trade volumes or trade flows to construct the international trade network. Some scholars studied the network using the social network theory. They discovered the network's core trading countries, trade centralization, and regionalism [8–12]. Wang et al. examined the network's density, centrality, cohesive subgroups, and core-edge structure. They discovered that the density has a fluctuating character that first decreases and then rises, and the network exhibits clear characteristics of the "core + half periphery + periphery" layer in its spatial structure evolution [13]. Wei conducted a centrality analysis and a block model analysis of the agricultural trade network between China and the "Belt and Road" countries and discovered that the network is complex, stable, and ranked [14]. Zhao et al. discovered that agricultural trade relations among the countries along the "Belt and Road" are becoming increasingly close and present a development trend of regional concentration [15]. Other scholars studied the network using complex network theory. They revealed the distribution of trade resources [16–19], trade division [20] and network evolution laws [21,22]. Cai et al. engaged with the issue of countries' positions in the international agricultural commodity trade using complex network theories [23]. Han et al. analyzed the structural characteristics and evolutionary trends of the trade network of marine energy products along the "Belt and Road", and the community structure and the relationships between China and various other trade communities were presented [24]. The second group concerns the study of the top networks in international trade. With the growth of global trade, the network of international trade relations has grown denser, which affects the analysis of the most important trade relations between countries. Some scholars proposed extracting the most important trade relations from the trade relations network, and the focus of this field of study is the

exploration of methods of constructing the top trade network [25,26]. The third group concerns the study of competitive and complementary networks of international trade. Scholars constructed competitive and complementary networks based on competitive and complementary indices between countries. Zhan constructed a competitive network and a complementary network of agricultural trade along the "Belt and Road". He found that the complementarity of agricultural trade is greater than the competition, and that there is a greater potential for cooperation between countries [27]. Xie et al. divided agricultural products into four categories and constructed competitive and complementary networks of four types of agricultural trade along the Belt and Road, respectively. They found that there are "competitive and complementary hubs" and triangle trade clusters in these networks [28].

According to a review of the literature, the agricultural international trade networks along the "Belt and Road" primarily include trade networks, competitive networks, and complementary networks. These previous studies primarily examined the structural characteristics of one or two types of networks in order to reach relevant conclusions and make relevant policy recommendations. However, they ignored the fact that trade, as well as competitive and complementary relations among countries, are interdependent rather than independent. Because of their interdependence, these three types of networks must be integrated into the analysis when developing national trade development policies. Taking Figure 1 as an example, if the complementary network between countries is examined independently, it can be concluded that country A has trade complementarity with both country B and country C. That is, country A has the potential to establish trade relations with both country B and country C. Furthermore, country A should adopt the same trade policies toward country B and country C. In fact, country A's trade policies toward country B and country C cannot be fully equivalent. Compared with country C, it is easier for country A to establish trade relations with country B. This is because country B has no other trading partners. When country A chooses to establish trade relations with country B, it does not need to consider the possibility of competing with country D for country C's market and can avoid trade conflicts with country D. Therefore, country A should prioritize establishing trade relations with country B. When the network is large, trade and competitive and complementary relations among the countries become intertwined and complex. We must combine these three types of networks and adopt scientific network analytical methods. Only in this way can we develop more scientific trade policies. However, to the best of our knowledge, there is no research exploring this issue, and the theoretical community also lacks a scientific approach that combines several networks in its analysis.

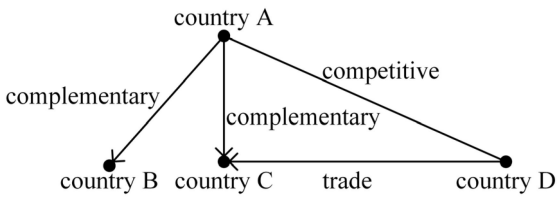


Figure 1. Diagram of the complex relations between countries.

In this paper, we take the relations in the international trade of western agricultural products along the "Belt and Road" as our research object and define a weighted super adjacency matrix that can combine the trade network, competitive network, and complementary network based on the super adjacency matrix [29–31]. The weighted super adjacency matrix is a partitioned matrix. The sub-matrices on the leading diagonal are intralayer relation matrices, which are used to describe the trade and competitive and complementary relations between countries, respectively. The sub-matrices on the non-leading diagonal are interlayer relation matrices, which are used to describe whether any two types of trade relations, competitive relations, and complementary relations exist simultaneously between two countries. We then propose scientific analytical methods,

including a classification algorithm for local network relations and a comparative analysis of trade development priorities based on local network relations. These can serve as a theoretical and methodological foundation for future research on international trade relations. Analyzing trade multilayer networks of western agricultural products in the "Belt and Road", we can identify key trading countries and potential trading countries of western agricultural products in the "Belt and Road", as well as the order of priority of the western region in trading with these countries. The findings of our study can serve as a foundation for the formulation of policies for the development of western agricultural international trade.

2. Materials

2.1. Research Objects

2.1.1. Belt and Road Countries

According to the "Belt and Road" official website, by December 2020, 137 countries had signed "Belt and Road" cooperation agreements with China. As a result, we define the scope of the "Belt and Road" countries and divide them into six regions, as shown in Table 1.

Table 1. "Belt and Road" countries.

Area	Countries
Asia	Korea, Mongolia, Singapore, Timor-Leste, Malaysia, Myanmar, Cambodia, Vietnam, Brunei, Iran, Nepal, Iraq, Pakistan, Sri Lanka, Bangladesh, Maldives, Kuwait, Turkey, Laos, Qatar, Oman, Lebanon, Saudi Arabia, Bahrain, Afghanistan, Azerbaijan, Georgia, Armenia, Kazakhstan, Yemen, Kyrgyzstan, Tajikistan, Uzbekistan, Thailand, Indonesia, United Arab Emirates, Philippines
Europe	Cyprus, Russia, Austria, Greece, Poland, Serbia, Czech Republic, Bulgaria, Slovakia, Croatia, Estonia, Italy, Moldova, Lithuania, Luxembourg, Montenegro, Slovenia, Hungary, Ukraine, North Macedonia, Belarus, Malta, Romania, Latvia, Portugal, Albania, Bosnia and Herzegovina
Africa	Sudan, South Africa, Senegal, Sierra Leone, Côte d'Ivoire, Somalia, Cameroon, South Sudan, Seychelles, Guinea, Ghana, Zambia, Mozambique, Gabon, Namibia, Mauritania, Angola, Togo, Djibouti, Ethiopia, Kenya, Nigeria, Chad, Congo-Brazzaville, Zimbabwe, Algeria, Tanzania, Burundi, Cape Verde Uganda, Gambia, Niger, Benin, Rwanda, Morocco, Madagascar, Tunisia, Libya, Egypt, Equatorial Guinea, Liberia, Lesotho, Comoros
Oceania	New Zealand, Papua New Guinea, Samoa, Fiji, Micronesia, Cook Islands, Tonga, Vanuatu, Kiribati, the Solomon Islands
South America	Chile, Guyana, Bolivia, Uruguay, Venezuela, Suriname, Ecuador, Peru.
North America	Costa Rica, Panama, El Salvador, Dominica, Trinidad and Tobago, Antigua and Barbuda, Dominica, Cuba, Grenada, Barbados, Jamaica

2.1.2. Important Agricultural Products in the Western Region

The western region of China involves 12 provinces, autonomous regions, and municipalities, namely Tibet, Xinjiang, Qinghai, Gansu, Shaanxi, Ningxia, Inner Mongolia, Sichuan, Chongqing, Yunnan, Guizhou, and Guangxi. This paper identifies the important agricultural products of each province, autonomous region, or municipality by collecting statistical yearbooks and relevant official reports. We then classify the important agricultural products using the Harmonized Commodity Description and Coding System (HS).

In Shaanxi Province, for example, the important agricultural products include edible mushrooms, konjac, apples, pomegranates, kiwis, jujubes, persimmons, walnuts, peppers, tea, and medicinal herbs. By examining the HS code, we can see that the first two HS code of edible mushrooms and konjac is HS07. The first HS code of apples, pomegranates, kiwis, dates, persimmons, and walnuts is HS08. The first HS code of peppers and tea is HS09. The first HS code of medicinal herbs is HS12. These all belong to category II, as plant products. The important agricultural products of the remaining 11 provinces, autonomous regions, and municipalities are classified in the same way as above.

Through the data collation, in this paper, we finally determine the western important agricultural products as follows: category I, including movable objects, animal products, comprising HS01–HS05 and a total of 5 product chapters; category II, comprising plant products, including HS06–HS14 and a total of 9 product chapters; and category IV, comprising food, beverages, wine and vinegar, tobacco, tobacco, and tobacco substitute products, including HS16–HS24 and a total of 9 product chapters. Detailed information is shown in Table 2.

Table 2. Important categories of agricultural products in the western region.

Area	Special Products and HS Two-Digit Codes	Categories
Tibet	Yak (HS01); Rhodiola (HS06); highland edible mushroom (HS07); ginseng fruit (HS08); barley rice (HS10); saffron (HS12); yak meat (HS16); water, beer, barley drink (HS22)	category I, II, IV
Xinjiang	Cattle, sheep (HS01); dairy (HS04); potato (HS07); condiment (HS09); wolfberry (HS12); Hami melon, grape, jujube, apple, pear, dried fruit (HS08); lamb (HS16); raisins (HS20)	category I, II, IV
Qinghai	Yak, Tibetan sheep (HS01); dairy (HS04); potato (HS07); barley rice, quinoa (HS10); canola, sea buckthorn (HS12); sea buckthorn drink, barley drink (HS22)	category I, II, IV
Gansu	Potato, carrot (HS07); apple (HS08); peppers (HS09); herbs (HS12)	category II
Shaanxi	Edible mushroom, konjac (HS07); pepper, tea (HS09); herbs (HS12); apple, pomegranate, kiwi, jujube, persimmon, walnut (HS08)	category II
Ningxia	Cattle, sheep (HS01); dairy (HS04); potato (HS07); wolfberry, licorice (HS12); wine (HS22)	category I, II, IV
Inner Mongolia	Cattle, sheep (HS01); dairy (HS04); potato (HS07); sunflower (HS12)	category I, II
Sichuan	White wine (HS22); tobacco (HS24)	category IV
Chongqing	Tangerine (HS08); Huang Lian, Codonopsis pilosula (HS12); orange juice, squash (HS20); condiments (HS21)	category II, IV
Yunnan	Flower (HS06); edible mushroom (HS07); walnut, fruit, vegetables (HS08); tea, coffee (HS09); Chinese herbs (HS12); healthcare products (HS21)	category II, IV
Guizhou	Edible mushroom (HS07); vegetables (HS08); tea, chillis (HS09); white wine (HS22); buckwheat, dendrobium, Chinese herbs, rapeseed (HS12); tobacco (HS24)	category II, IV
Guangxi	Grapefruit, kumquat (HS08); tea (HS09)	category II

As shown in Table 2, category I agricultural products are mainly distributed among Tibet, Xinjiang, Qinghai, Ningxia and Inner Mongolia; category II agricultural products are mainly distributed among Tibet, Xinjiang, Qinghai, Gansu, Shaanxi, Ningxia, Inner Mongolia, Chongqing, Yunnan, Guizhou and Guangxi; and category IV agricultural products are mainly distributed among Tibet, Xinjiang, Qinghai, Ningxia, Sichuan, Chongqing, Yunnan and Guizhou.

2.2. Research Data

Agricultural international trade data were obtained from the UN Comtrade database. Focusing on western agricultural products, we obtained trade import and export data of HS01–HS05, HS06–HS14 and HS16–HS24 between China and the "Belt and Road" countries of 2020 from the UN Comtrade database. This serves as the data source for the abstract description and analysis of the multilayer networks of western agricultural trade in the "Belt and Road".

3. Model

3.1. Matrix Description of Multilayer Network of Trade Relations

Based on the super adjacency matrix [29–31], this paper defines a weighted super adjacency matrix $M = (A, O)$, which is used to construct the multilayer network of trade relations. $A = \{X, Y, Z\}$ denotes the set of matrices of intralayer relations in the multilayer network of trade relations, where X is the matrix of trade relations, Y is the matrix of competitive relations, and Z is the matrix complementary relations, which are used to describe the trade relations, competitive relations, and complementary relations among countries, respectively. $O = \{XY, XZ, YZ\}$ denotes the set of matrices of interlayer relations in the multilayer network of trade relations, where XY is the matrix of trade–competition interlayer relations, XZ is the matrix of trade–complementarity interlayer relations, and YZ is the matrix of competition–complementarity interlayer relations, which are used to describe whether two certain types of relations exist between countries at the same time.

According to the above definition, the weighted super adjacency matrix of the multilayer network of trade relations can be represented as follows.

$$M = \begin{pmatrix} X & XY & XZ \\ XY & Y & YZ \\ XZ & YZ & Z \end{pmatrix} \tag{1}$$

3.2. Construction of the Weighted Super Adjacency Matrix

3.2.1. Construction of the Intralayer Relation Matrices

(1) Construction of the matrix of trade relations

Based on the construction method of directed weighted networks in the literature [22], we construct the matrix of agricultural trade relations $X = (V_1,\ E_1)$ with countries as nodes, trade relations as edges, and trade volumes as weights. Among these, $V_1 = \{V_1^1,\ V_1^2, \cdots,\ V_1^n\}(n = 1,\ 2, \cdots,\ 138)$ is the set of nodes in the network layer of trade relations, $E_1 = \{X_{11},\ X_{12}, \cdots,\ X_{ij}, \cdots,\ X_{nn}\}(n = 1,\ 2, \cdots,\ 138;\ i, j = 1,\ 2, \cdots,\ n)$ is the set of edges in the network layer of trade relations. When $X_{ij} > 0$, this means that there is a trade relation between country i and country j, and the weight is X_{ij}. When $X_{ij} = 0$, this means that there is no trade relation between country i and country j.

The matrix of trade relations X can be expressed as follows.

$$X = \begin{bmatrix} X_{11} & X_{12} & \cdots & X_{1,138} \\ X_{21} & X_{22} & \cdots & X_{2,138} \\ \vdots & \vdots & \ddots & \vdots \\ X_{138,1} & X_{138,2} & \cdots & X_{138,138} \end{bmatrix} \tag{2}$$

(2) Construction of matrix of competitive relations

This paper uses the export similarity index ESI in the literature [32] to measure the competitive relations between countries. It is calculated as Equation (3):

$$ESI_{ij}^n = \sum_k \left[\frac{x_{ik}/x_{in} + x_{jk}/x_{jn}}{2} \times \left(1 - \left| \frac{x_{ik}/x_{in} - x_{jk}/x_{jn}}{x_{ik}/x_{in} + x_{jk}/x_{jn}} \right| \right) \right] \times 100 \tag{3}$$

In the equation above, ESI_{ij}^n denotes the export similarity index between country i and country j in category n agricultural products. x_{jk} denotes country j's export value on agricultural products in chapter k of category n, and x_{jn} denotes country j's total export value on agricultural products in category n. According to the method of literature [27], this paper constructs the matrix of competitive relations of agricultural trade $Y = (V_2,\ E_2)$. Among them, $V_2 = \{V_2^1,\ V_2^2, \cdots,\ V_2^n\}(n = 1,\ 2, \cdots,\ 138)$ is the set of nodes in the network layer of competitive relations, and $E_2 = \{Y_{11},\ Y_{12}, \cdots, Y_{ij}, \cdots, Y_{nn}\}(n = 1,\ 2, \cdots,\ 138; i, j = 1,\ 2, \cdots,\ n)$ is the set of edges in the network layer of competitive relations. When $ESI_{ij}^n > 50$, $Y_{ij} = ESI_{ij}^n$, this indicates that the export structure is similar between country i and country j. That

is, there is a competitive relation between country i and country j, and the weight is Y_{ij}. Otherwise, $Y_{ij} = 0$, indicating that there is no competitive relation between country i and country j.

The matrix of competitive relations Y can be expressed as follows.

$$Y = \begin{bmatrix} Y_{11} & Y_{12} & \cdots & Y_{1,138} \\ Y_{21} & Y_{22} & \cdots & Y_{2,138} \\ \vdots & \vdots & \ddots & \vdots \\ Y_{138,1} & Y_{138,2} & \cdots & Y_{138,138} \end{bmatrix} \tag{4}$$

(3) Construction of the matrix of complementary relations

The paper uses the complementary index TCI in the literature [33] to measure the complementary relations between countries. It is calculated as Equation (5):

$$TCI_{ij}^{n} = \sum_{k} TCI_{ijk} \times \frac{x_{wk}}{x_{wn}} = \sum_{k} RCA_{xik} \times RCA_{mjk} \times \frac{x_{wk}}{x_{wn}} \tag{5}$$

In Equation (5), the RCA is calculated as shown in Equation (6):

$$RCA_{xik} = \frac{x_{ik}/x_{in}}{x_{wk}/x_{wn}}, RCA_{mjk} = \frac{m_{jk}/m_{jn}}{m_{wk}/m_{wn}} \tag{6}$$

Above, TCI_{ij}^{n} is the complementary index between country i and country j for category n agricultural products. The meanings of x_{ik} and x_{in} are the same as in Equation (3). Moreover, x_{wk} denotes the export value placed by all the "Belt and Road" countries on agricultural products in chapter k of category n, x_{wn} denotes the total export value placed by all the "Belt and Road" countries on agricultural products in category n, and m represents the import. According to the method of the literature [27], this paper constructs the matrix of complementary relations of agricultural trade $Z = (V_3, E_3)$. Among them, $V_3 = \{V_3^1, V_3^2, \cdots, V_3^n\} (n = 1, 2, \cdots, 138)$ is the set of nodes in the network layer of complementary relations, and $E_3 = \{Z_{11}, Z_{12}, \cdots, Z_{ij}, \cdots, Z_{nn}\}$ $(n = 1, 2, \cdots, 138; i, j = 1, 2, \cdots, n)$ is the set of edges in the network layer of complementary relations. When $TCI_{ij}^{n} > 1$, $Z_{ij} = TCI_{ij}^{n}$, this indicates that there is a complementary relation between country i's exports and country j's imports, and the weight is Z_{ij}. Otherwise, $Z_{ij} = 0$, indicating that there is no complementary relation between country i and country.

The matrix of complementary relations Z can be expressed as follows:

$$Z = \begin{bmatrix} Z_{11} & Z_{12} & \cdots & Z_{1,138} \\ Z_{21} & Z_{22} & \cdots & Z_{2,138} \\ \vdots & \vdots & \ddots & \vdots \\ Z_{138,1} & Z_{138,2} & \cdots & Z_{138,138} \end{bmatrix} \tag{7}$$

3.2.2. Construction of the Matrices of Interlayer Relations

The interlayer connections of the multilayer network of trade relations indicate whether any two types of trade relations, competitive relations, or complementary relations exist simultaneously between countries.

According to the above definition, this paper constructs the matrix of trade–competition interlayer relations $XY = (V_1, V_2, E_{12})$. Among them, V_1 and V_2 are the sets of nodes in the layer of trade relations and the layer of competitive relations, respectively. Moreover, $E_{12} = \{XY_{11}, XY_{12}, \cdots, XY_{ij}, \cdots, XY_{nn}\} (n = 1, 2, \cdots, 138; i, j = 1, 2, \cdots, n)$ is the set of interlayer connections between the layer of trade relations and the layer of competitive relations. Note that XY_{ij} can be calculated by Equation (8). When $XY_{ij} = 1$, there is a connected edge between node i in the layer of trade relations and node j in the layer

of competitive relations, indicating that there is both a trade relation and a competitive relation between country i and country j. Otherwise, $XY_{ij} = 0$.

$$XY_{ij} = \begin{cases} 1 & X_{ij} \neq 0 \text{ and } Y_{ij} \neq 0 \\ 0 & \text{otherwise} \end{cases} \tag{8}$$

The matrix of complementary relations Z can be expressed as follows:

$$XY = \begin{bmatrix} XY_{11} & XY_{12} & \cdots & XY_{1,138} \\ XY_{21} & XY_{22} & \cdots & XY_{2,138} \\ \vdots & \vdots & \ddots & \vdots \\ XY_{138,1} & XY_{138,2} & \cdots & XY_{138,138} \end{bmatrix} \tag{9}$$

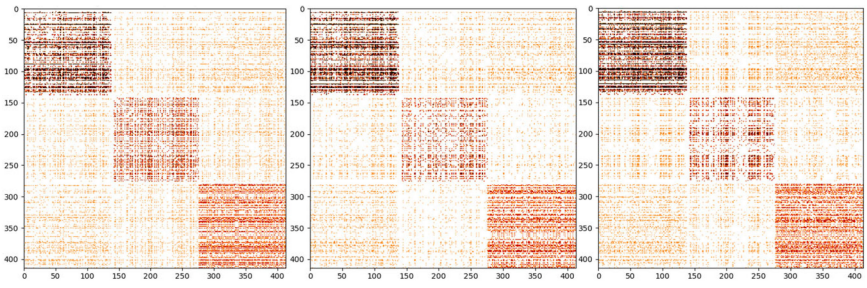
This paper defines and constructs the trade-complementary interlayer relations matrix $XZ = [XZ_{ij}]$ and the matrix of competition–complementary interlayer relations $YZ = [YZ_{ij}]$ using the same method as above. Here, $XZ_{ij} = 1$ means that there is both a trade relation and a complementary relation between country i and country j. Moreover, $YZ_{ij} = 1$ means that there is both a competitive relation and a complementary relation between country i and country j.

3.2.3. Construction of Weighted Super Adjacency Matrix

According to the matrices of intralayer relations built in Section 3.2.1 and matrices of interlayer relations built in Section 3.2.2, this paper builds the weighted super adjacency matrix. The specific information is shown in matrix M':

$$M' = \begin{bmatrix} X_{11} & \cdots & X_{1,138} & XY_{11} & \cdots & XY_{1,138} & XZ_{11} & \cdots & XZ_{1,138} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ X_{138,1} & \cdots & X_{138,138} & XY_{138,1} & \cdots & XY_{138,138} & XZ_{138,1} & \cdots & XZ_{138,138} \\ XY_{11} & \cdots & XY_{1,138} & Y_{11} & \cdots & Y_{1,138} & YZ_{11} & \cdots & YZ_{1,138} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ XY_{138,1} & \cdots & XY_{138,138} & Y_{138,1} & \cdots & Y_{138,138} & YZ_{138,1} & \cdots & YZ_{138,138} \\ XZ_{11} & \cdots & XZ_{1,138} & YZ_{11} & \cdots & YZ_{1,138} & Z_{11} & \cdots & Z_{1,138} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ XZ_{138,1} & \cdots & XZ_{138,138} & XYZ_{138,1} & \cdots & YZ_{138,138} & Z_{138,1} & \cdots & Z_{138,138} \end{bmatrix} \tag{10}$$

Using the trade import and export data obtained in Section 2.2, this paper constructs weighted super adjacency matrices of the western various agricultural products along the "Belt and Road", which are $M'1$, $M'2$, and $M'3$. To better understand $M'1$, $M'2$, and $M'3$, we use a heat map [34,35] to visualize them, as shown in Figure 2.



(a) category I (b) category II (c) category IV

Figure 2. Weighted super adjacency matrices of various agricultural products.

3.3. Construction of the Multilayer Network of Trade Relations

Based on the weighted super adjacency matrices $M'1$, $M'2$, and $M'3$ built in Section 3.2, we use Python to visualize the multilayer network of trade relations of the western various agricultural products. We take category I agricultural products as an example and construct its topology of multilayer network of trade relations. Since the network is very dense, we adopt a method used in the literature [25] and extract the top10 matrices from the matrix of trade relations X, matrix of competitive relations Y, and matrix of complementary relations Z, respectively. We then construct the weighted super adjacency top10 matrices, as shown in Figure 3a. Based on this, we construct the top10 topology of the category I agricultural multilayer network of trade relations, as shown in Figure 3b.

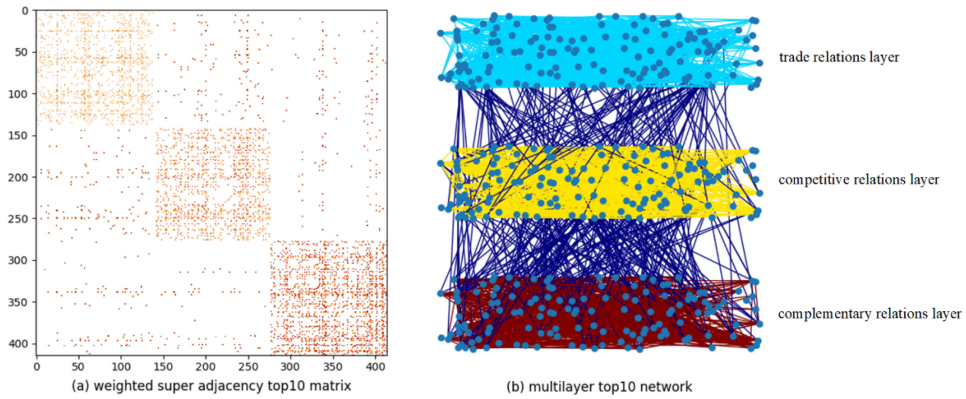


Figure 3. Category I agricultural multilayer top10 network.

4. Methods and Results

4.1. Methods

The existing social network analytical methods and complex network analytical methods cannot solve the problem presented in this paper. Therefore, based on the weighted super adjacency matrix M' of the multilayer network of trade relations, this paper proposes analytical methods for complex relations of a multilayer trade network, including a classification algorithm of local network relations and a comparative analysis of trade development priorities based on local network relations.

4.1.1. Local Network Relations: Classification Algorithm for Key Trading Countries and Potential Trading Countries

The classification algorithm of local network relations is mainly used to identify a country's key trading countries and potential trading countries along the "Belt and Road" and to classify their local network relations. The algorithm analytical flow is shown in Figure 4 and can be described as follows.

The first step involves identifying the key trading countries and potential trading countries of country i among the "Belt and Road" countries. The analytical process is shown in the dashed box in the first step of Figure 4 and can be described as follows.

First, we analyze the matrix of trade–complementary interlayer relations XZ and the matrix of complementary relations Z in the weighted super adjacency matrix M'. According to $XZ_{ij} = 1$, one can select country j from among the "Belt and Road" countries that has both a trade relation and a complementary relation with country i and define it as a class A key trading country of country i. According to $XZ_{ij} = 0$ and $Z_{ij} > 0$, one can select country j from among the "Belt and Road" countries that only has a complementary relation with country i and define it as a class B potential trading country of country i. If $XZ_{ij} = 0$ and $Z_{ij} = 0$, this means that country j is neither a class A key trading country nor a class B potential trading country of country i, and we end the analysis.

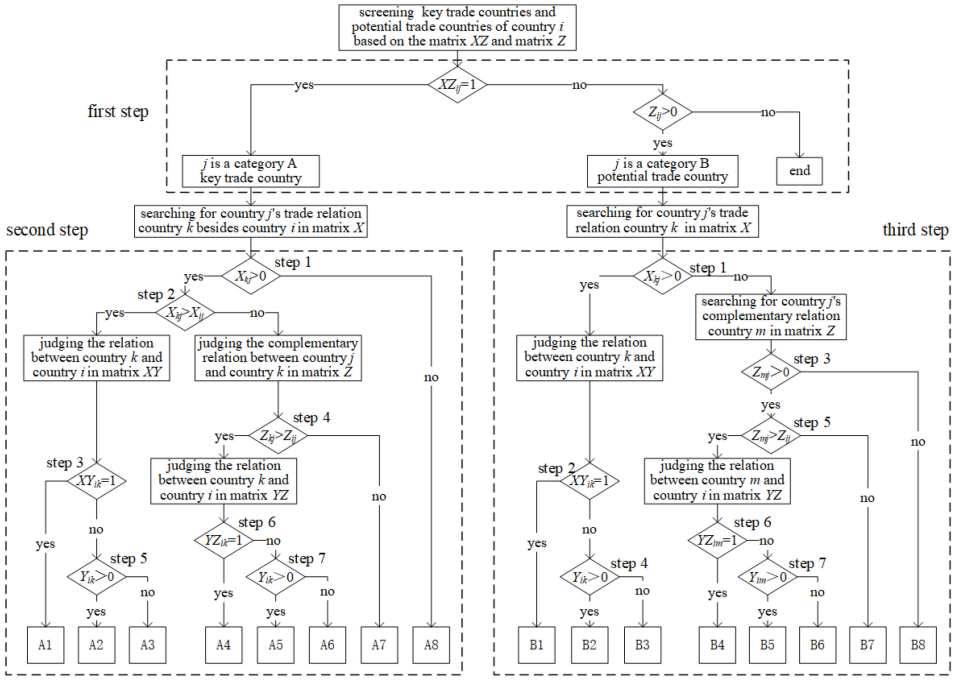


Figure 4. Algorithm analytical flow of the multilayer network of trade relations.

The second step involves analyzing the local network relations between country *i* and the class A key trading countries and classifying the class A key trading countries. The entire analytical process is depicted in the dashed box in the second step of Figure 4, which can be described as steps 1–7 below.

Step 1: judge whether the key trading country *j* has trading partners other than country *i*. The specific process is as follows.

We start by analyzing the matrix of trade relations *X* in the weighted super adjacency matrix M' to judge if $X_{kj} > 0$ holds. If it does, we will conclude that country *j* has other trading partners besides country *i* and move on to step 2; if it does not, we will conclude that country *j* has no other trading partners. In this case, the local network structure between country *j* and country *i* is depicted in Figure 5a, and country *j* is classified as an A8 country.

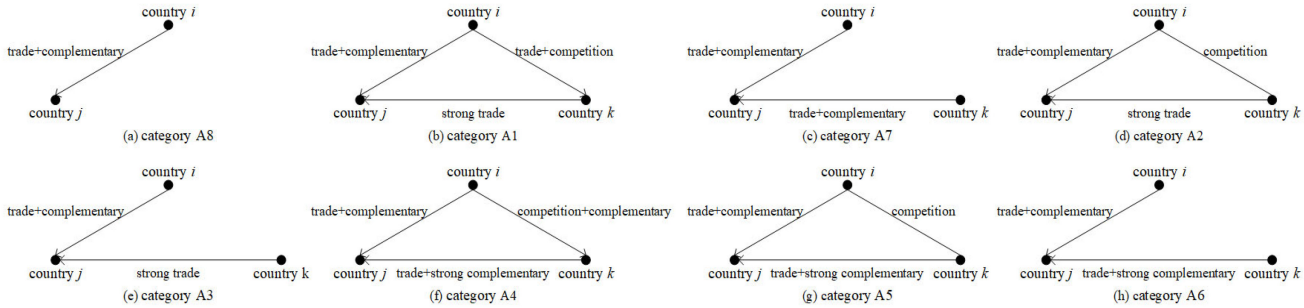


Figure 5. Classification of local network relations for category A key trading countries.

Step 2: judge the strength of the trade relations between country *j* and country *k*. The specific process is as follows.

We analyze the matrix of trade relations *X* in the weighted super adjacency matrix M' to judge if $X_{kj} > X_{ij}$ holds. If it does, we will conclude that the trade relation between country *j* and country *k* is stronger than that between country *j* and country *i* and move on to step 3; if it does not, we move on to step 4.

Step 3: judge the relations between country i and country k. The specific process is as follows.

We start by analyzing the matrix of trade–competition interlayer relations XY in the weighted super adjacency matrix M' to judge if $XY_{ik} = 1$ holds. If it does, we will conclude that there is both a trade relation and a competitive relation between country i and country k. Combining the results of steps 1–3, we can see that the local network structure between country j and country i is depicted in Figure 5b, and country j is classified as an A1 country. If it does not, we will move on to step 5.

Step 4: judge the strength of the complementary relations between country j and country k. The specific process is as follows.

We start by analyzing the matrix of complementary relations Z in the weighted super adjacency matrix M' to judge if $Z_{kj} > Z_{ij}$ holds. If it does, we will conclude that the complementary relation between country j and country k is stronger than that between country j and country i and move on to step 6; if it does not, we will conclude that the complementary relation between country j and country k is not stronger than that between country j and country i. Combining the results of steps 1–2 and 4, we can see that the local network structure between country j and country i is depicted in Figure 5c, and country j is classified as an A7 country.

Step 5: judge the competitive relation between country i and country k. The specific process is as follows.

We start by analyzing the matrix of competitive relations Y in the weighted super adjacency matrix M' to judge if $Y_{ik} > 0$ holds. If it does, we will conclude that there is a competitive relation between country i and country k. Combining the results of steps 1–3 and 5, we can see that the local network structure between country j and country i is depicted in Figure 5d, and country j is classified as an A2 country. If it does not, we will conclude that there is no competitive relation between country i and country k. Combining the results of steps 1–3 and 5, we can see that the local network structure between country j and country i is depicted in Figure 5e, and country j is classified as an A3 country.

Step 6: judge the relation between country i and country k. The specific analysis is as follows.

We start by analyzing the matrix of competition–complementary interlayer relations YZ in the weighted super adjacency matrix M' to judge if $YZ_{ik} = 1$ holds. If it does, we will conclude that there is both a competitive relation and a complementary relation between country i and country k. Combining the results of steps 1–2, 4 and 6, we can see that the local network structure between country j and country i is depicted in Figure 5f, and country j is classified as an A4 country. If it does not, we will move on to step 7.

Step 7: judge the competitive relation between country i and country k. The specific process is as follows.

We start by analyzing the matrix of competitive relations Y in the weighted super adjacency matrix M' to judge if $Y_{ik} > 0$ holds. If it does, we will conclude that there is a competitive relation between country i and country k. Combining the results of steps 1–2, 4, 6, and 7, we can see that the local network structure between country j and country i is depicted in Figure 5g, and country j is classified as an A5 country. If it does not, we will conclude that there is no competitive relation between country i and country k. Combining the results of steps 1–2, 4, 6, and 7, we can see that the local network structure between country j and country i is depicted in Figure 5h, and country j is classified as an A6 country.

The third step involves analyzing the local network relations between country i and the Class B potential trading countries and classifying the class B potential trading countries. The algorithm analytical process is depicted in the dashed box in the third step of Figure 4, which is similar to the second step and is not repeated. The final classification results are depicted in Figure 6.

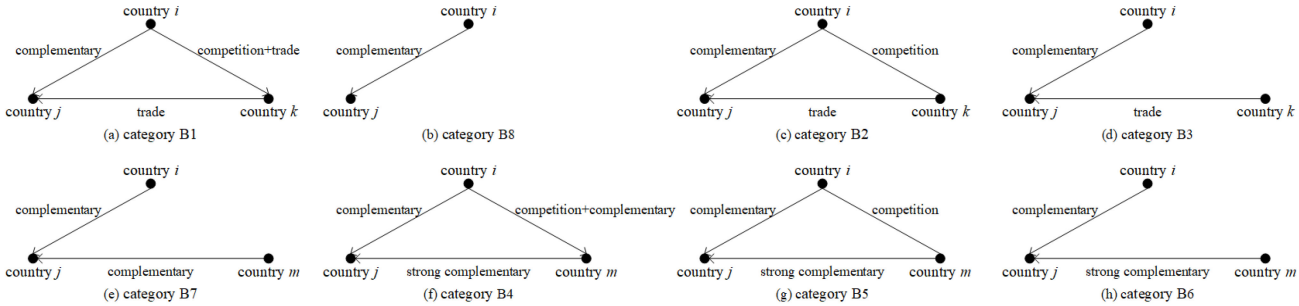


Figure 6. Classification of local network relations for category B potential trading countries.

4.1.2. Comparative Analysis of the Trade Development Priorities Based on Local Network Relations

Based on the above classification results of the key trading countries and potential trading countries, this paper compares and analyzes the economic connotations of the local network structure. Following this step, the paper clarifies the order of priority for maintaining trade relations between country *i* and eight types of key trading countries and the order of priority for establishing trade relations between country *i* and the eight types of potential trading countries. During the process of analysis, the paper uses the symbol ">" to indicate the order of priority. The specific analytical process is as follows.

1. Comparative analysis of the key trading countries' trade development priorities

First, inspecting each subplot in Figure 4, we discover that the local network structure of the countries in category A8 is the simplest. Countries in categories A7, A3, and A6 have the most similar local network structures to the countries in category A8. Countries in categories A4 and A5 have the most similar local network structures to the countries in category A6. Countries in categories A1 and A2 have the most similar local network structures to the countries in category A3.

Secondly, we conduct the following comparative analysis based on similar local network structures.

(1) Comparative analysis of the countries in categories A8, A7, A3, and A6

① Category A8 countries have no other trading partners besides country *i*. Country *i* does not need to be concerned that other countries will compete with it for the market of category A8 countries. Therefore, it is enough for country *i* to maintain existing trade relations with category A8 countries.

② Compared with category A8 countries, category A7 countries have a trade relation and a complementary relation with country *k* in addition to country *i*. In order to prevent the trade relations between category A7 countries and country *k* from developing further and affecting the relations between category A7 countries and country *i*, country *i* should consider strengthening its trades relation with category A7 countries. That is, A7 > A8.

③ Compared with category A7 countries, category A6 countries have a strong complementary relation with country *k*. This indicates that the potential for trade development between category A6 countries and country *k* is greater than that between category A6 countries and country *i*. The former are more likely to develop into strong trade partners and thus threaten the trade relations between country *i* and category A6 countries. Therefore, country *i* should prioritize strengthening the maintenance of trade relations with category A6 countries. That is, A6 > A7.

④ Compared with category A6 countries, category A3 countries have a strong trade relation with country *k*. In order to avoid losing its trade relations with category A3 countries completely, country *i* should prioritize strengthening the maintenance of trade relations with category A3 countries. That is, A3 > A6.

(2) Comparative analysis of the countries in categories A6, A4 and A5

① Compared with the local network structure of category A6 countries, there is a competitive relation between country *i* and country *k* in the local network structure of category A5 countries. This indicates that the export structure of country *i*'s products is very

similar to that of country *k*'s products, and that they are in fierce competition. Therefore, country *i* should prioritize strengthening the maintenance of trade relations with category A5 countries, which will facilitate country *i* in competing with country *k* for country *j*'s market in a highly competitive environment. That is, A5 > A6.

② Compared with the local network structure of category A6 countries, there is also a competitive relation between country *i* and country *k* in the local network structure of category A4 countries. As stated above, country *i* should prioritize strengthening the maintenance of trade relations with category A4 countries. That is, A4 > A6.

③ Compared with the local network structure of category A5 countries, there is a complementary relation between country *i* and country *k* in the local network structure of category A4 countries. This indicates that country *i* has the potential for trade development with country *k* in addition to category A4 countries. It can develop country *k* as a trade partner. Therefore, for country *i* maintaining trade relations with category A4 countries is a lower priority. That is, A5 > A4.

(3) Comparative analysis of countries in categories A3, A1, and A2

① Compared with the local network structure of category A3 countries, there is a competitive relation between country *i* and country *k* in the local network structure of category A2 countries. This indicates that the export structure of country *i*'s products is very similar to that of country *k*'s products, and that they are in fierce competition. Therefore, country *i* should prioritize strengthening the maintenance of trade relations with category A2 countries, which will facilitate country *i* in competing with country *k* for country *j*'s market in a highly competitive environment. That is, A2 > A3.

② Compared with the local network structure of category A3 countries, there is also a competitive relation between country *I* and country *k* in the local network structure of category A1 countries. As stated above, country *i* should give priority to strengthening the maintenance of trade relations with category A1 countries. That is, A1 > A3.

③ Compared with the local network structure of category A2 countries, there is a trade relation between country *i* and country *k* in the local network structure of category A1 countries. This indicates that country *i* develops trade with country *k* in addition to category A1 countries, and its trade partners are selective. Therefore, country *i* gives less priority to maintaining trade relations with category A1 countries. That is, A2 > A1.

Based on the above analysis, we can obtain two order of priority of trade development results, namely A5 > A4 > A6 > A7 > A8 and A2 > A1 > A3 > A6 > A7 > A8. Further comparative analysis of the order between A2 > A1 > A3 and A5 > A4 is required for the countries that have not yet been prioritized. Compared with countries in categories A5 and A4, countries in categories A2, A1, and A3 all have a strong trade relations with country *k*. Therefore, country *i* should prioritize strengthening the maintenance of trade relations with countries in categories A2, A1, and A3 to avoid losing these important trading partners completely. That is, A2 > A1 > A3 > A5 > A4.

Summarizing the results of the above analysis, we can obtain that the order of priority for country *i* in strengthening the maintenance of trade relations with the eight categories of key trading countries is A2 > A1 > A3 > A5 > A4 > A6 > A7 > A8.

2. Comparative analysis of the trade development priorities of potential trading countries

Using the same comparative analytical method as that used for the key trading countries, we can obtain the order of priority for country *i* in establishing trade relations with the eight categories of potential trading countries. This is B8 > B7 > B6 > B4 > B5 > B3 > B1 > B2.

4.2. Results

Based on the methods proposed in Section 4.1, this paper employs Python to analyze the weighted super adjacency matrices $M'1$, $M'2$, and $M'3$, respectively. The findings identify the key trading countries and potential trading countries for the trade of western important agricultural products among the "Belt and Road" countries, as well as the order p of priority for trade development. The details are as follows.

First, in category I agricultural trade, this paper identifies 37 key trading countries and 1 potential trading country from among the "Belt and Road" countries. Based on the local network structure, these 37 key trading countries are divided into 6 types. According to the trade development order of priority, they are 4 A2 countries, 9 A1 countries, 10 A3 countries, 9 A5 countries, an A6 country, and 4 A8 countries. A potential trading country is Chile. The details are shown in Table 3.

Table 3. Results of the analysis of the multilayer network of relations for category I agricultural trade.

Type	Countries
A2	Ecuador, Jamaica, Nigeria, Costa Rica
A1	Italy, Tunisia, Togo, Cameroon, Côte d'Ivoire, Zambia, Mali, South Korea, South Africa
A3	Ghana, Gabon, Malaysia, Indonesia, Poland, Myanmar, Benin, Papua New Guinea, Samoa, Solomon Islands
A5	New Zealand, Philippines, Portugal, Dominica, Thailand, Kenya, Suriname, Uruguay, Rwanda
A6	Vietnam
A8	Morocco, Uganda, Federated States of Micronesia, Burundi
B3	Chile

Secondly, in category II agricultural trade, this paper identifies 49 key trading countries from among the "Belt and Road" countries. Based on the local network structure, they are divided into three types. According to the trade development order of priority, they are 28 A1 countries, 5 A3 countries, and 16 A5 countries. The details are shown in Table 4.

Table 4. Results of the analysis of the multilayer network of relations for category II agricultural trade.

Type	Countries
A1	Serbia, Croatia, Slovakia, Czech Republic, Hungary, Luxembourg, Moldova, Bulgaria, Poland, Estonia, Ukraine, Lithuania, Kuwait, Bahrain, Seychelles Islands, Slovenia, Cape Verde, Ecuador, Laos, Maldives Uruguay, Algeria, Chile, Dominica, El Salvador, Solomon Islands, Cook Islands, Singapore
A3	Barbados, UAE, Sri Lanka, Costa Rica, Fiji
A5	Russia, Myanmar, New Zealand, Morocco, Nepal, Indonesia, Vietnam, Thailand, Korea, Malaysia, Mauritania, Kazakhstan, Pakistan, Gambia, Guyana, Suriname

Thirdly, in category IV agricultural trade, this paper identifies 62 key trading countries from among the "Belt and Road" countries. Based on the local network structure, they are divided into six types. According to the trade development priority order, they are 41 A1 countries, 6 A3 countries, 7 A5 countries, 6 A4 countries, 1 A6 country, and 1 A8 country. The details are shown in Table 5.

In order to better present and analyze the research results and then formulate development strategies for western agricultural trade, this paper divides the eight categories of key trading countries into four levels based on their orders priority for trade development. The first level includes A2 and A1 countries; the second level includes A3 and A5 countries; the third level includes A4 and A6 countries; and the fourth level includes A7 and A8 countries. On the basis of Tables 3–5, the paper employs ArcGis to draw the results of the level division of key trading countries for various agricultural products on the map, as shown in Figure 7. There is only one potential trading country in category I agricultural products. The result is already obvious. Therefore, the analysis is not shown in Figure 7.

Table 5. Results of the analysis of the multilayer network of relations for category IV agricultural trade.

Type	Countries
A1	Austria, Romania, Kuwait, Qatar, Antigua and Barbuda, Saudi Arabia, Italy, Barbados, Equatorial Guinea, Comoros, Sudan, Ukraine, Morocco, Kenya, Gambia, Bahrain, Tanzania, Cuba, Ethiopia, Jamaica, Micronesia, Portugal, Mali, Bolivia, Burundi, OECS, Peru, Egypt, Bangladesh, Ecuador, Rwanda, Seychelles, Philippines, Russia, Yemen, Uruguay, Kazakhstan, Zambia, Cape Verde, Gabon, El Salvador
A3	Vanuatu, New Zealand, Dominica, Papua New Guinea, Costa Rica, Kiribati
A5	Togo, Benin, Algeria, Cameroon, Sierra Leone, Chile, Thailand
A4	Ghana, Nigeria, Korea, Sri Lanka, Solomon Islands, Cote d'Ivoire
A6	Samoa
A8	Fiji

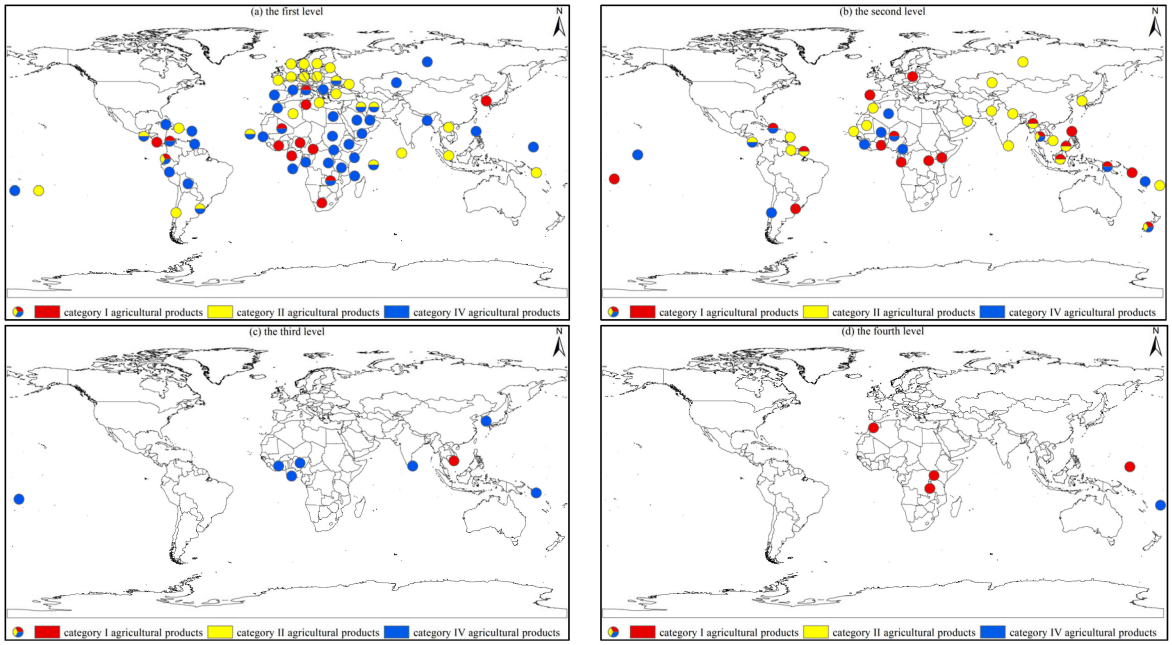


Figure 7. Results of the level division of the key trading countries.

Observing the subplots in Figure 7, this paper shows that, from the distribution of the number of countries, the key trading countries are mainly concentrated in the first level and the second level. From the categories of agricultural products, we can see that the key trading countries of category I agricultural products and category IV agricultural products are distributed in four levels, while the key trading countries of category II agricultural products are only distributed in the first level and the second level. The first level and the second level contain the four categories of key trading countries with the highest priority for trade development out of the eight categories. The above information indicates that it is very urgent for the western region to strengthen its agricultural trade relations with the key trading countries, especially with the countries in the first level and the second level.

Further analyzing Figure 7a, we find that Ecuador is a first-level key trading country for each of the three categories of agricultural products; Jamaica, Italy, Zambia, and Mali are first-level key trading countries for category I and category IV agricultural products; and Ukraine, Kuwait, Bahrain, Seychelles Islands, Cape Verde, Uruguay, and El Salvador are first-level key trading countries for category II and category IV agricultural products. Further analyzing Figure 7b, we find that New Zealand and Thailand are second-level key trading countries for each of the three categories of agricultural products; Malaysia,

Indonesia, Myanmar and Suriname are second-level key trading countries for category I and category II agricultural products; Benin, Papua New Guinea and Dominica are second-level key trading countries in category I and category IV agricultural products; and Costa Rica is a second-level key trading countries for category II and category IV agricultural products.

The provinces, municipalities, and autonomous regions in the western region should focus on agricultural trade cooperation with the abovementioned countries according to their specific agricultural categories. The details are as follows.

Category I agricultural products in the western region include live animals and animal products, which are primarily distributed among Tibet, Xinjiang, Qinghai, Ningxia, and Inner Mongolia. In regard to category I agricultural products, these five provinces or autonomous regions should give top priority to enhancing their trade relations with Ecuador, Jamaica, Italy, Zambia, and Mali. They should also focus on maintaining trade relations with New Zealand, Thailand, Malaysia, Indonesia, Myanmar, Benin, Suriname, Papua New Guinea, and Dominica.

Category II agricultural products in the western region are plant products, which are primarily distributed among Tibet, Xinjiang, Qinghai, Gansu, Shaanxi, Ningxia, Inner Mongolia, Chongqing, Yunnan, Guizhou, and Guangxi. In regard to category II agricultural products, these 11 provinces, autonomous regions, or municipalities should give top priority to enhancing trade relations with Ecuador, Ukraine, Kuwait, Bahrain, Seychelles Islands, Cape Verde, Uruguay, and El Salvador. They should also focus on maintaining trade relations with New Zealand, Thailand, Malaysia, Indonesia, Myanmar, Suriname, and Costa Rica in regard to category II agricultural products.

Category IV agricultural products in the western region are foods, beverages, tobacco and other products, which are primarily distributed among Tibet, Xinjiang, Qinghai, Ningxia, Sichuan, Chongqing, Yunnan, and Guizhou. In regard to category IV agricultural products, these eight provinces, autonomous regions, or municipalities should give top priority to enhancing trade relations with Ecuador, Jamaica, Italy, Zambia, Mali, Ukraine, Kuwait, Bahrain, Seychelles Islands, Cape Verde, Uruguay. and El Salvador. They should also focus on maintaining trade relations with New Zealand, Thailand, Benin, Papua New Guinea, Dominica. and Costa Rica in regard to category IV agricultural products.

5. Discussion and Conclusions

This paper investigated the relations in the international trade of important western agricultural products along the "Belt and Road" from a network perspective. Firstly, the paper defined a weighted super adjacency matrix to combine trade and competitive and complementary networks and then innovatively employed the interlayer relations to construct the multilayer trade network model. Secondly, the paper proposed complex relations analytical methods, including a local network relation classification algorithm for key and potential trading countries and a trade development priority comparison based on the local network relations. The paper revealed the key and potential trading countries of the western region along the "Belt and Road" by analyzing the multilayer networks of important western agricultural products and clarified the order of priority for trade development. Finally, the paper divided the key trading countries into levels, and then devised the western agricultural trade development strategies for trade with the "Belt and Road" countries.

There are 37 key trading countries and one potential trading country in the "Belt and Road" countries for category I agricultural products in the western region. These key trading countries are divided into four levels according to the order priority for trade development. Category II agricultural products relate to 49 key trading countries in the Belt and Road countries, which are divided into two levels according to the trade development priority. Category IV agricultural products relate to 62 key trading countries in Belt and Road countries, which are divided into four levels according to the priority order of trade development. These key countries for the trade of various agricultural products are mainly

clustered in the first level, with the highest trade development priority, and the second level, with the second level of priority. At the same time, some of the key trading countries are in the first level or second level across multiple categories of agricultural trade.

The western region should focus on strengthening the maintenance of trade relations with key trading countries in the first level and the second level and, especially, the need to strengthen trade relations with countries that are first-level or second-level key trading countries in at least two categories of agricultural trade. Specifically, in accordance with their own specific agricultural product categories, the provinces, municipalities, and autonomous regions of the western region should give top priority to enhancing trade cooperation with 12 key trading countries, namely Ecuador, Jamaica, Italy, Zambia, Mali, Ukraine, Kuwait, Bahrain, Seychelles, Cape Verde, Uruguay, and El Salvador. They should also focus on maintaining trade cooperation with New Zealand, Thailand, Malaysia, Indonesia, Myanmar, Suriname, Benin, Papua New Guinea, Dominica, and Costa Rica, which are all key trading countries. These provinces, municipalities, and autonomous regions urgently need to develop trade relations with the aforementioned countries in regard to at least two categories of agricultural products. Meanwhile, the western region should actively maintain good trade relations with 18 key trading countries in regard to category I agricultural products, such as Nigeria, Tunisia, and Togo, and proactively establish trade relations with Chile, a potential trading country. The western region should also actively maintain good trade relations with 34 key trading countries in regard to category II agricultural trade, such as Serbia, Croatia and Slovakia, and 44 key trading countries in regard to category IV agricultural trade, such as Austria, Romania, and Qatar.

However, admittedly, this paper has the following limitations: (1) The trade multilayer relationship network in this paper is constructed by means of matrix expression. Meanwhile, the analytical methods are proposed based on the weighted super adjacency matrix. In future research, we will try to construct the trade multilayer relationship network by using the aggregation expression or tensor expression and propose the related analytical method. (2) This paper uses cross-sectional data when constructing the trade multilayer relationship network, and we cannot study the dynamic changes in the network. In future research, we will further construct a model of the dynamic evolution of the trade multilayer relationship network in order to study the deeper properties and dynamic evolution law of the network and to explore further information about it.

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