Resources Policy 63 (2019) 101417

Contents lists available at ScienceDirect

Resources Policy

journal homepage: www.elsevier.com/locate/resourpol

Who will trade bauxite with whom? Finding potential links through link prediction☆

sen Liu, Zhiliang Dong*

School of Management Science and Engineering, Hebei GEO University, China

ARTICLE INFO

Keywords:
Bauxite
International trade
Potential partners
Link prediction

ABSTRACT

In order to find potential links in bauxite international trade and help bauxite trading countries find new partners as well as diversify trading partners. A link prediction approach was used to find potential bauxite trade links from the perspective of the topological relationship of trade networks in various countries and trade rules. The results show that over the next five to six years, Denmark and the United States, China and Hungary; Guinea and the Netherlands, Hungary and the United States; and Australia and the United Kingdom are most likely to establish bauxite trade relations. However, Brazil and Turkey, Guyana and Hungary are the least likely to trade bauxite. The results of this study show that we can understand the potential changing trends of the international bauxite trade and provide relevant government policy recommendations for it.

1. Introduction

It is well known that countries with poor bauxite resources usually establish and gradually expand trade relations with bauxite-rich countries to meet their demand for bauxite and maintain the security of their bauxite supply. At the same time, there are potential trade links between countries. In fact, predicting and evaluating these potential trade link relationships (Duan, 2008) is important for researchers in exploring bauxite trade relationships between countries. Although potential trade relations between countries may not always be obvious, trade relations between countries can be affected by their interactions and trade patterns (Ji et al., 2014), which will prompt them to change their trade relations in the future. Researchers can therefore assess hidden trade links by looking for potential trade link relationships. In addition, finding potential trade relationships is also important for governments because this discovery will help them understand the international trade in bauxite and reduce trade risks. Based on the above situation and the patterns of the international bauxite trade, this paper explores the potential link relationships of the international bauxite trade from a new perspective.

In recent years, with the rapid development of the aluminium industry, trade between countries has become more frequent. The trade volume of bauxite has increased every year, and research on bauxite has also increased. Some scholars have extended their research on aluminium to a global scale, creating a global circuit of aluminium through the establishment of a multi-layer material flow analysis model linked to trade (Gang and Müller, 2013). Other scholars have studied the treatment and utilization of bauxite waste residue from the perspective of environmental protection (Bird et al., 1989; Yalçın and Sevinç, 2000; Wehr et al., 2006). Some scholars have tried to use GDP or monetary unions to predict the trade flows of known trade links (Duan, 2008; Foschi et al., 2013). In addition, Shi and other scholars have studied the evolution characteristics of the international bauxite trade from the perspective of complex networks (Shi et al., 2018). However, these studies are based on the exploration or evaluation of obvious trade relationships. With the expansion of the international bauxite trade network, international trade relations have continued to be affected, and new trade relations have also been promoted. The purpose of this study is to find new partners for countries, so a new approach is needed to find potential trade relationships that do not exist but may emerge in the future. The link prediction based on network topology is an approach to explore future potential links (Lü and Zhou, 2011), and there is a research gap in regard to applying this approach to predict the international trade relationship for bauxite.

As an emerging research approach (Aaron et al., 2008), research related to link prediction mostly involves the improvement of the algorithm used in the approach and the innovation of the new algorithm. For example, the Adamic/Adar (AA) algorithm was proved by Liben-Nowell and Kleinberg as the most predictive approach (Liben-Nowell and Kleinberg, 2003). Subsequently, Zhou Tao et al. proposed a more

☆ Full postal address: School of Management Science and Engineering, Hebei GEO University, Shijiazhuang province, China.
* Corresponding author.
E-mail address: dongzhl@126.com (Z. Dong).

https://doi.org/10.1016/j.resourpol.2019.101417
Received 19 February 2019; Received in revised form 24 May 2019; Accepted 31 May 2019
Available online 03 July 2019
0301-4207/

accurate algorithm based on the above research, namely, Resource Allocation (RA), which is based on resource allocation (Zhouet al., 2009). There is also a Preference Attachment (PA) algorithm based on the preference connection between two nodes. The PA algorithm is widely used to explore the dynamic network relationship (Chuan-Yang et al., 2006; Petter et al., 2002; Guo-Qing et al., 2007). In addition, link prediction is also used to explore interpersonal networks (Sherkat et al., 2015; Shi et al., 2015; Ahmad et al., 2012), biological networks (Almansoori et al., 2011), transportation networks (Terekhov et al., 2015; Kong et al., 2013), trading networks (Trattner et al., 2014), criminal networks (Berlusconi et al., 2016), and so on. Guan used the Common Neighbour (CN) algorithm to predict potential trade links in the international oil trade network (Guan et al., 2016); Feng used the PA algorithm to explore the formation rules of the link relationship in the international LPG trade network (Feng et al., 2017). They used the trade network to detect the accuracy of the algorithm and proved that these algorithms are effective in finding potential trade link relationships. Therefore, this paper uses the link prediction approach to find potential trade links in international bauxite trade relations. We explore the potential trade motives behind existing trade relations by analysing the characteristics of the trade network formed by the countries participating in the bauxite trade.

This paper assesses potential trade links based on real trade relationships to provide a new perspective on trade relations between countries participating in the bauxite trade. To explore the motivation of the international bauxite trade, this paper first uses the four current mainstream link prediction algorithms to calculate the score of the trade and find the optimal algorithm. Then, based on the obtained link prediction result and the actual trade relationship, the prediction effect is evaluated. Finally, by dividing the international bauxite trade participants into different trade roles, the accuracy of the forecast is improved, and the potential trade links are given a clearer and more instructive meaning. By comparing the role of the bauxite trade in different countries, a further practical understanding of potential trade links is developed. This paper predicts potential trade links that are formed by actual trade relations.

The remainder of the paper is organized as follows. Section 2 describes the data and methodological steps used in this paper. Section 3 describes the process of finding potential links and analyses the empirical results. Section 4 contains for discussion and summary, including predictions for future trade relations.

2. Data and methodology

2.1. Data

The annual bauxite import and export data used in this paper were downloaded from the United Nations Statistics Division (https://comtrade.un.org/) on December 25, 2018. The time span is a total of ten years from 2008 to 2017, and the HS code is 260,600. Year, Reporter Code, Trade Flow Code (including import and export), Partner Code, Classification, Commodity Code, Quantity Unit Code, Supplementary Quantity, Netweight (kg), Value and Estimation Code are included in the download data. According to the research needs, we selected the Year, Reporter Code, Trade Flow Code, Partner Code and Netweight (kg). We then removed the codes that did not represent a country-specific partnership, the reporters and partners representing the same country's partnerships and the repeated trade relationships. In addition, when the trade volume reported by the exporting country differed from the trade volume reported by the importing country, the larger number was selected because the reporting of the smaller one may be due to negligence.

Fig. 1 shows the national trades in the global bauxite trade in 2008, 2013 and 2017, the links between countries indicate the bauxite trade relationship between countries. In addition, some important trading countries have been marked. The size of the nodes in the figure is divided according to the number of trading partners. The larger the node, the more trading partners it has. The thick or thin edge between the nodes indicates the trade volume between the two countries. The thicker the edge, the greater the trade volume is between the two countries. It can be seen from the figure that the locations of major trading nations are changing constantly over time, the international bauxite trade networks are complicated and different countries are in different positions. Moreover, whether it is from the perspective of the evolution of the trade network or from the perspective of data volume and research methods, it is sufficient to select trade data for ten years.

2.2. Methodology

2.2.1. Construction of the international bauxite trade network

Since the main purpose of this paper is to predict the future trade of bauxite based on existing trade relations, the issue focuses on which trade countries will trade bauxite in the next few years. Instead of exploring which country will import or export bauxite from where. In other words, what we have studied in this paper is the creation of trade relations. So, we made predictions based on undirected network.

The undirected weighted network of the international bauxite trade is constructed using a complex network approach. As shown in Fig. 1, the nodes represent the countries involved in bauxite trading, and the edges represent the actual trade relations between the countries. The weight of each edge represents the trade volume (kg) of bauxite. Because there is a total of ten years of data and a network is built based on each year, a total of 10 complex international bauxite trade networks are obtained.

2.2.2. Link prediction model

Link prediction based on complex networks has been successfully applied to some papers on international trade (Vidmer et al., 2015; Tuninetti et al., 2016). This paper mainly introduces the structural drivers and potential links of the international bauxite trade links. Fig. 2 shows a simple process of link prediction.

The specific steps of this paper are as follows:

Step 1: Choose the optimal algorithm

It is necessary to select the optimal algorithm to explore the network link characteristics of the international bauxite trade. The current mainstream algorithms are Common Neighbour (CN), Adamic/Adar (AA), Resource Allocation (RA), and Preferential Attachment (PA), and these algorithms have been proven effective in previous complex network research, so this paper selects these four algorithms for research and selects the optimal algorithm by comparison. The four algorithms will be introduced below, and the four algorithms will be defined in conjunction with the actual international bauxite trade.

(1) Common Neighbour (CN algorithm). If two nodes have more co-neighbour nodes, then the two nodes are similar. That is, the more trading partners of two national nodes, the greater the possibility is of trade between the two countries. There are two equations for the CN algorithm, one is the unweighted algorithm that does not consider the trade volume, as shown in equation (1), and the other is the weighted algorithm that considers the trade volume, as shown in equation (2).

$$S_{xy}^{CN} = |\Gamma(x) \cap \Gamma(y)| \tag{1}$$

Returning to international bauxite trade, x and y in equation (1) represent two countries participating in international bauxite trade. $\Gamma(x)$ represents the set of countries that have trade relations with country x, and $\Gamma(x)\Gamma(y)$ represents the number of countries that have direct trade relations with the two countries x and y.

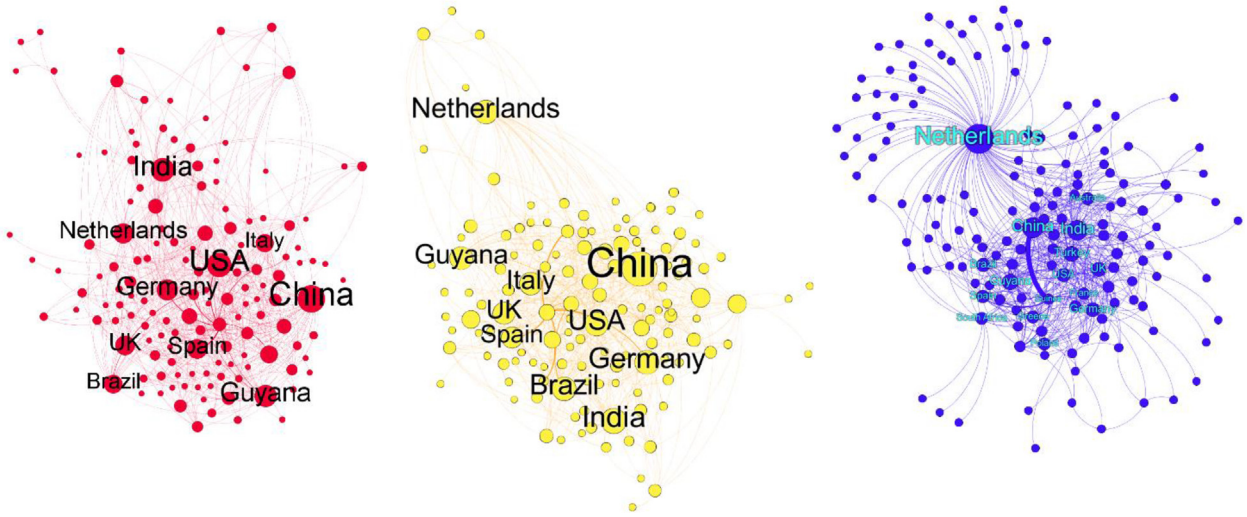


Fig. 1. Bauxite international trade network in 2008, 2013 and 2017.

$$S_{xy}^{CN} = \sum_{z \in \Gamma(x) \cap \Gamma(y)} \frac{w(x,z) + w(z,y)}{2} \tag{2}$$

In the international bauxite trade, z in equation (2) represents the common trading partner of bauxite trading countries x and y, and $w(x, z)$ represents the trade volume between country x and country z.

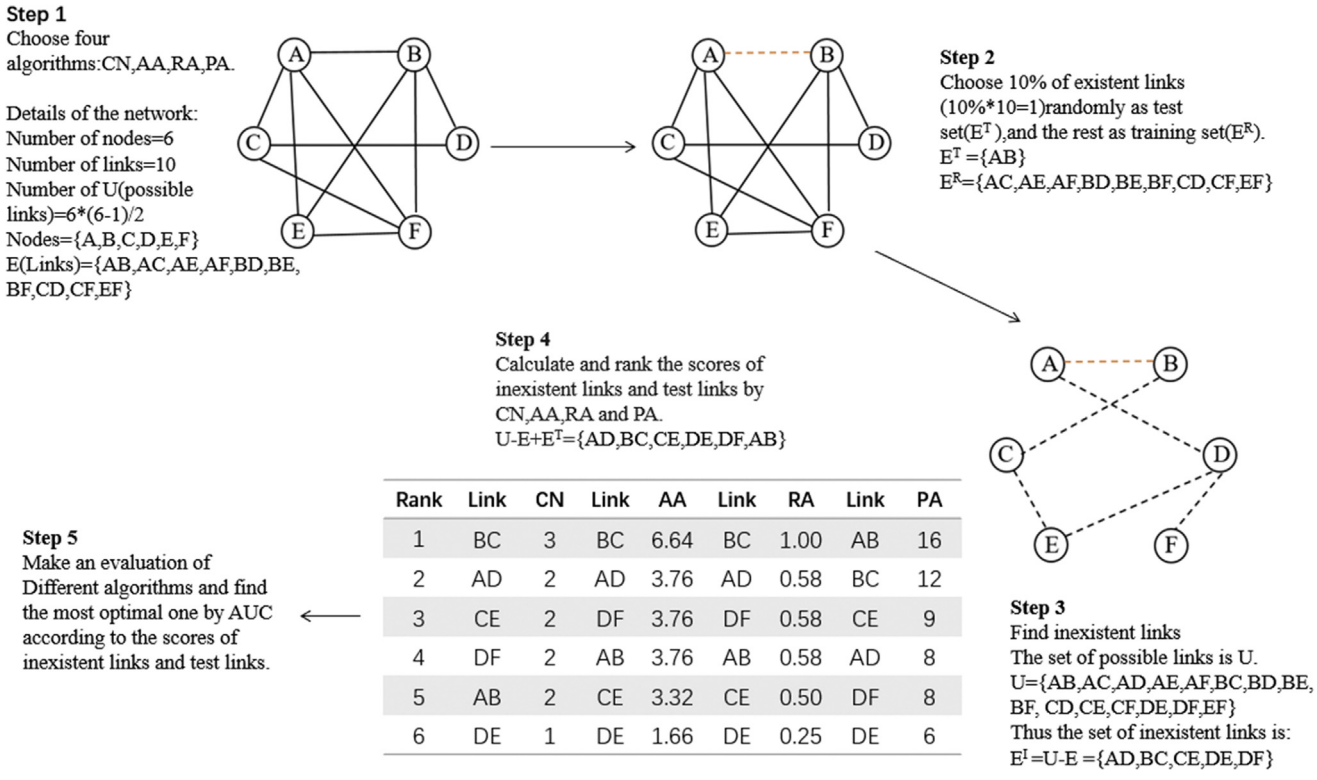
(2) Adamic/Adar (AA algorithm). The idea of this algorithm is that the contribution of a co-neighbour node with a small degree is greater than that of a co-neighbour node with a large degree.

$$S_{xy}^{AA} = \sum_{z \in \Gamma(x) \cap \Gamma(y)} \frac{1}{logk_z} \tag{3}$$

$$S_{xy}^{CN} = \sum_{z \in \Gamma(x) \cap \Gamma(y)} \frac{w(x,z) + w(z,y)}{\log(1 + S(z))} \tag{4}$$

In equation (3), k_z is the number of countries with direct trade links with country z. In equation (4), $S(z) = \sum_{i \in \Gamma(z)} w(z, i)^{\alpha}$ and i denotes a country that generates trade relationship with the country z.

(3) Resource Allocation (RA algorithm). Zhou Tao and others have built an RA algorithm that is similar to the AA algorithm. In the RA algorithm, considering two countries x and y without direct trade links, the common neighbour is seen as a medium of communication between the two trading countries. If the influence of trade volume is considered, it is calculated by equation (6).



Rank	Link	CN	Link	AA	Link	RA	Link	PA
1	BC	3	BC	6.64	BC	1.00	AB	16
2	AD	2	AD	3.76	AD	0.58	BC	12
3	CE	2	DF	3.76	DF	0.58	CE	9
4	DF	2	AB	3.76	AB	0.58	AD	8
5	AB	2	CE	3.32	CE	0.50	DF	8
6	DE	1	DE	1.66	DE	0.25	DE	6

Fig. 2. Schematic diagram of the link prediction algorithm.

$$S_{xy}^{RA} = \sum_{z \in \Gamma(x) \cap \Gamma(y)} \frac{1}{k_z} \tag{5}$$

$$S_{xy}^{RA} = \sum_{z \in \Gamma(x) \cap \Gamma(y)} \frac{w(x,z) + w(z,y)}{S(z)} \tag{6}$$

(4) Preferential Attachment (PA algorithm). The countries with more trading partners, the easier it is to establish new trade relationships. See equation (7). If the influence of trade volume is considered, it is calculated by equation (8).

$$S_{xy}^{PA} = |\Gamma(x)| \times |\Gamma(y)| \tag{7}$$

$$S_{xy}^{PA} = \sum_{j \in \Gamma(x)} w(x,j) \times \sum_{q \in \Gamma(x)} w(y,q) \tag{8}$$

In equation (8), j represents a country with a direct trade relationship with country x, and similarly, q represents a country with a direct trade relationship with country y.

Step 2: Divide the data into training sets and the test set

To further test the accuracy of the algorithm, 10% of the existing trade links (E) were randomly used as the test set, denoted as E^T, and the remaining 90% of the trade links were used as training sets (Lü and Zhou, 2011), denoted as E^R.

$$E = E^T + E^R \quad and \quad E^T = 10\% * E \tag{9}$$

Step 3: Find the link relationships that do not exist

Implicit trade link relationships generally arise from links that do not exist. If we want to predict the trade relationships, we first need to find the link relationships that do not exist. Assuming that there are n countries participating in the international bauxite trade, then U, all trade link relationships between these participating countries, can be calculated by equation (10). Therefore, the set of link relationships that do not exist can be calculated by equation (11).

$$U = \frac{n * (n-1)}{2} \tag{10}$$

$$E^I = U - E \tag{11}$$

Step 4: Sort the test set and the non-existing link relationship set according to the four algorithms

The CN, AA, RA, and PA mainstream algorithms are used to calculate the test set and the non-existent link relationship set, and we sort the links according to the algorithm score. The higher the score, the more likely the link is to be transformed into an existing link in the future, which means that the country corresponding to the link is more likely to have a trade relationship in the future.

Step 5: Evaluate each algorithm and choose the optimal algorithm

Area under the receiver operating characteristic curve (AUC), ranking score and precision are three commonly used indicators to measure the accuracy of link prediction algorithms. AUC measures the accuracy of the algorithm from a holistic perspective. The ranking score considers the position of the edge in the test set in the final sort. The precision considers whether the edge of the top L position is accurate. The latter two focus only on the local information (Lü and Zhou, 2011). Since this paper explores the formation of international bauxite trade relations for the entire trade network, AUC is chosen as the predictive accuracy evaluation index.

AUC can be understood as the probability of randomly selecting the edges of a test set whose score is higher than the score of randomly selecting a non-existent edge. That is, each time randomly selects an edge from the test set and the non-existing link relationship set. If the score of the test set edge is higher, then 1 point is added, if the scores of the two sides are equal, then 0.5 points are added. Repeat the comparison for n times, where n' represents the number of times the score in the test set is higher than the score of the non-existent link relationship set, and n'' represents the number of equal scores on both sets (Fawcett, 2005).

$$AUC = \frac{n' + 0.5n''}{n} \tag{12}$$

From equation (12), if all the scores are randomly generated, then $AUC \approx 0.5$, and the degree of AUC greater than 0.5 measures the accuracy of the corresponding algorithm compared to the random selection link. That is, the higher the AUC score, the more accurate the corresponding algorithm.

2.2.3. Analysis model of the international bauxite trade

Although the link prediction model provides a new analytical perspective for the drivers of international bauxite trade relations, the development status of the bauxite industry varies from country to country. To obtain a more accurate and realistic trade relationship, based on the evaluation of the validity of the link prediction model and the discovery of potential trade rules, we construct an international analysis model of bauxite that links the physical topology features of the link prediction with the trade characteristics. Specific steps are as follows:

Step 1: Compare potential links with actual links to verify the validity of the link prediction model

The actual effectiveness of the link prediction model is tested by comparing the potential trade relations and actual trade relations from 2008 to 2017. For example, in 2008, the optimal algorithm predicted that a potential trade relationship will occur; the relationship then occurred after 2008. If most of the potential trade links predicted by the link prediction model are implemented in the next few years, this shows that this optimal algorithm is effective both theoretically and practically. In addition, since this study explores potential links in the international trade of bauxite in the next few years, there may be links that require further evaluation.

Step 2: Divide the role of the international bauxite trade and explore the trade rules

To explore the practical significance of potential trade links and potential trade link rules, this paper divides the countries involved in international bauxite trade into different roles. According to the trade data obtained, the top ten countries that appear in the potential trade links are divided into net importing countries and net exporting countries. The division rules are as follows:

$$D_t = \begin{cases} E_t, E_{Xt} - I_{Mt} > 0 \\ I_t, E_{Xt} - I_{Mt} < 0 \end{cases} \tag{13}$$

where t represents the year and D_t represents the role assigned to a country in the t-th year. If the export volume (E_{Xt}) of a country is greater than the import volume (I_{Mt}), then the country is classified as a net exporter (E_t) in the t-th year; otherwise, the country is classified as a net importer (I_t).

3. Results and discussion

3.1. Selecting the optimal algorithm

To determine the potential law of the international trade relationship of bauxite, this part compares the accuracy index AUC

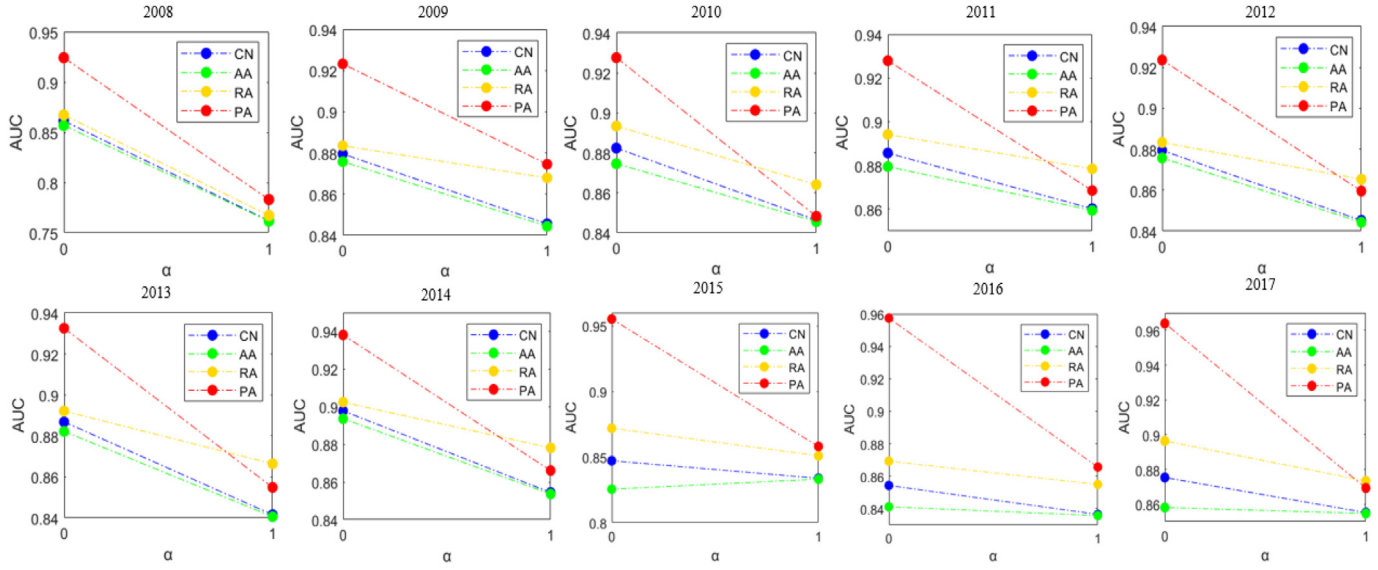


Fig. 3. Evaluation of four algorithms for 2008–2017 (dashed lines represent trends in AUC changes).

Table 1
Top 18 trade connections for 2012 PA value.

Rank	Country or region A	Country or region B	PA value	Link's type
1	China	Netherlands	2640	P
2	Germany	Netherlands	2120	T
3	Netherlands	UK	1680	T
4	China	Australia	1650	T
5	Italy	Brazil	1512	P
6	India	Spain	1462	P
7	Denmark	USA	1408	T
8	Denmark	India	1376	P
9	Guyana	India	1333	P
10	France	USA	1320	T
11	France	UK	1260	T
12	Denmark	Brazil	1152	T
13	Guyana	Brazil	1116	P
14	Germany	United Arab Emirates	1113	P
15	Australia	India	1075	P
16	China	Slovenia	1056	T
17	Australia	Netherlands	1000	P
18	Denmark	Guyana	992	P

corresponding to the four algorithms. The higher the AUC score, the higher the accuracy of the corresponding algorithm. Therefore, the algorithm with the highest AUC score can be selected to predict the potential trade relationship.

Fig. 3 shows the AUC scores of the four algorithms, where $\alpha = 0$ represents that the influence of the transaction volume is not considered, and $\alpha = 1$ represents that the influence of the transaction volume is considered. The dashed line represents the general trend of AUC changes with α. The larger the AUC, the better the algorithm is. Therefore, by comparing the AUC scores, we have found that the optimal algorithm in all ten years is the PA algorithm when $\alpha = 0$, which shows that when using the PA algorithm to predict new trade links, more or less trade volume is equally important to the creation of new trade relations. Because the AUC score is higher without considering the volume of trade, the PA algorithm without considering the trade volume is used for prediction. To minimize random errors, the AUC score here is the average of 10 experiments. Each of the 10 experiments randomly divided the annual data into 10% test sets and 90% training sets. In addition, the AUC scores are all greater than 0.5 and are close to 1, so it is concluded that the PA algorithm is the optimal algorithm in this study.

In summary, in the new trade relationship predicted by the PA algorithm, countries with large trade volumes are as important as countries with small trade volumes. The number of trading partners owned by the countries participating in the bauxite trade has a positive effect on the formation of international bauxite trade relations.

3.2. Comparison of potential trade links and actual trade links

From the previous section, the PA algorithm is considered the optimal algorithm for discovering potential trade links in this study, and the PA algorithm has the highest score when the trade volume is not considered. Therefore, this paper sorts the test set and the non-existent link relationship by PA value without considering the trade volume. Previously, it has been proven that countries with more trading partners are more likely to generate new trade relations, so countries with the highest PA value have a greater possibility of establishing trade relationships. That is, the top-ranked and previously non-existent links are potential trade-country pairs that are more likely to establish trade relationships in the future.

To explore potential trade rules, this study selects the top ten non-existent links for each year from 2008 to 2017 and observes whether those links actually establish trade relations after being predicted.

Taking the year of 2012 as an example, Table 1 shows the top 18 trading countries or regions with the highest PA algorithm scores, including test links and links that do not exist. Among them, the first column of Table 1 represents the PA value ranking, and the second and third columns represent the two countries or regions of the trade link. The fourth column represents the PA value of the trade link country/region, and the fifth column represents the type of link. *T* is the link in the test set and *P* is the potential trade link. It can be seen that there are eight pairs of trade relations from the test set. The remaining ten pairs of trade relationships come from non-existent link relationships, which are potential trade links that require further analysis and are considered to be the top ten potential trade links. Therefore, the link relationship in which the annual PA value is ranked in the top ten and does not exist is selected to see if it actually has a trade relationship in the following years.

Fig. 4 shows the top ten potential trading countries or regions from 2008 to 2017. Since some trading countries repeatedly appear in the top ten in different years, there are 42 pairs of countries in the figure. For each row, the green fill patch indicates that the country did not trade bauxite for the corresponding year in this column. However, because they are in the top ten rankings of PA value, they are potential trade links. The yellow fill patch indicates that the pair of countries

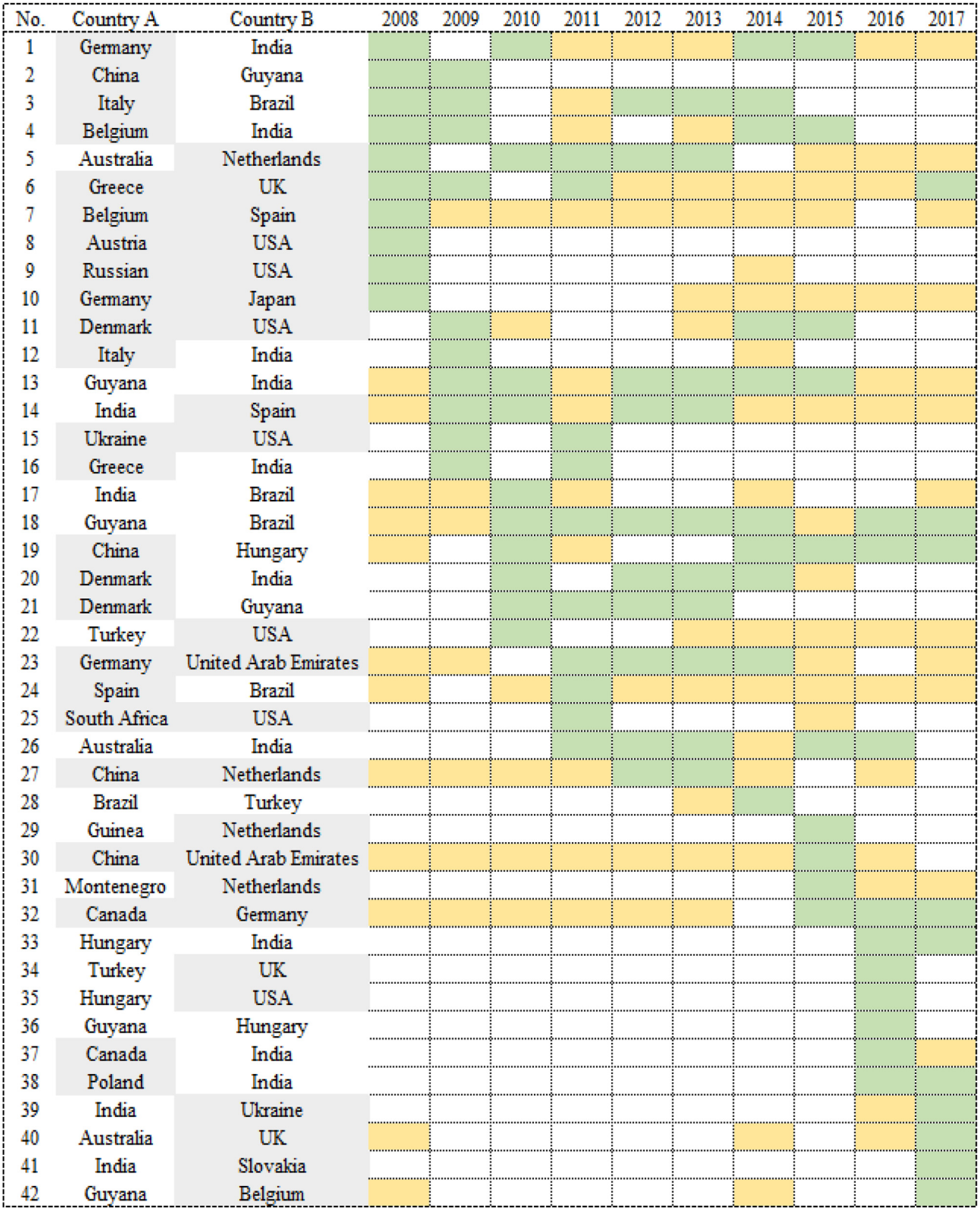


Fig. 4. Test links and potential links comparison from 2008 to 2017. (Grey-highlighted countries are net importers and unhighlighted are net exporters).

traded bauxite in the year corresponding to this column. Combined with the bauxite trade data obtained by the United Nations Statistics Division from 2008 to 2017, 42 pairs of trade links can be compared in 2008-2017 by observing potential trade links and existing trade links.

For each country pair corresponding to each row, if at least one yellow fill patch appears after the green fill patch, this indicates that the potential trade link did occur. Then, these countries are defined as successful predictions. Take the first pair of countries in Fig. 4, Germany and India, as an example. A potential trade relationship between the two was predicted in 2010, and the bauxite trade relationship became a reality in 2011, so they are a link that was successfully predicted. Conversely, if a yellow fill patch does not appear after the green

fill patch, they are called invalid predictions. Similarly, as shown in Fig. 4, the second pair of countries was predicted to develop trade relations in 2008 and 2009. However, in the following eight years, no bauxite trade relationship developed between China and Guyana, so they were invalid predictions.

In addition, the validity of the prediction algorithm can be further verified by comparing how many pairs of potential trade relationships were successfully predicted. As seen from Figs. 4 and 25 (60%) of the 42 countries had a successful prediction, indicating that the PA algorithm is effective in finding potential relationships in the international bauxite trade.

3.3. Further classification of potential trade links

By comparing the test links with potential links from 2008 to 2017, it can be found that although most of the potential trade links were successfully predicted in the subsequent several years, there were still some links that have yet to establish a real trade relationship despite being in the top ten. To obtain further results, this paper classified the 42 pairs of potential trade links into three categories according to whether they actually established a trade relationship. Next, these three categories of potential trade links will be further analysed.

The first category includes 25 pairs of countries that were successfully predicted at least once. As shown in Fig. 5, 22 pairs (88%) of bauxite-trading countries established trade relations within five years after their first appearance in the top ten potential trade links, while the remaining three pairs of trading countries have also had trade relations for up to six years. It can therefore be concluded that if a pair of countries appears in the top ten potential trade links in a given year, they are likely to establish bauxite trade relations in the next five to six years. Based on this, it can also be inferred that the countries that have appeared in the top ten potential trade links since 2013 but have not actually established bauxite trading relations still have the possibility of trading. Such pairs of countries include Italy and Brazil and China and Hungary. These countries are still considered to have potential trade links.

The second category includes the top ten potential trade links that appeared in 2017, as shown in Table 2. Because of the lack of relevant trade data after 2017, it is impossible to verify whether the top ten potential trade links in 2017 can generate real trade relations. According to the inference made from the first category, this paper argues that the top ten potential links that appeared in 2017 are the country pairs that will form a true trade relationship in the next five to six years.

The third category includes the countries that are in top ten potential trade links but have never truly had a trade relationship. As shown in Table 3, the letter *P* indicates that the country is in the top ten trade links in the year represented by that column, and *T* indicates that the country actually traded in the year corresponding to that column. A total of 17 countries have not successfully formed a trade relationship, and they need to be further evaluated in the next analysis to understand why they failed to link successfully.

3.4. Analysis of trade roles in the international bauxite trade

Although the link prediction based on the PA algorithm has certain validity, as seen above, there are still pairs of countries that have not yet successfully traded (17 pairs). To a certain extent this reflects the shortcomings of link prediction based on physical topology networks. The international trade network of bauxite is complicated. The prediction results based on the physical trade topology and the characteristics of international bauxite trade must be improved. Therefore, this paper divides the countries or regions involved in the international bauxite trade into different trade roles, namely, net importers of bauxite and net exporters of bauxite. In addition, we explore and apply trade rules by observing trade roles to identify the most tradeable links in the top 10 potential trade links.

A country's role can be determined based on the import and export volume. According to the downloaded trade data, the trade role of each country in the corresponding year is obtained by calculating the import and export volume.

First, if the export volume is higher than the import volume within one year, a country is regarded as a net exporter. Otherwise, it is a net importer. Take Table 2 as an example. In 2017, countries with bold names were net importers, while countries without bold names were net exporters.

Second, the final role of each country is determined using the annual trade data for each country. The role of all potential trading countries in the years 2008 to 2017 is shown in Table 4. The net exporting country is indicated by "*E*" and filled with pink. The net importing country is indicated by "*I*" and filled with grey, and "0" means that the import volume is equal to the export volume. In addition, it is stipulated that if the role of a country has not changed for ten years, it is finally defined as the very role. Countries such as Australia (No. 1), Brazil (No. 2), and Guyana (No. 3) are finally defined as net exporters. Countries such as Canada (17) and China (18) are finally defined as net importers. If a country's role changes within a decade, it may be due to the country's reserves and production, so the country's final role is defined according to the role of the most recent year and is marked in yellow. For example, Greece (No. 7) was a net exporter before 2014, but it was transformed into a net importer in 2014; it has remained one ever since. This change identifies Greece as a net importer.

3.5. Explore link rules for potential trades

The following potential link rules are summarized by observing the PA value as well as by combining the successfully predicted trade relationships, the links that were not successfully predicted, and the dividing roles. Based on these rules, the most tradeable links can be selected from the potential links derived from the topology, although this does not mean that other potential links will not establish a real trade relationship. Trade link rules are as follows:

(1) In the potential international bauxite trade links, countries with a trade relationship of more than one year from 2008 to 2017 are more likely to trade bauxite in the future.

In general, of the trade countries that were successfully predicted (25 pairs), 18 pairs (72%) had bauxite trade relations for more than one year. This shows that countries involved in international bauxite trade are more likely to trade with their familiar partners. In Table 3, among the countries that were never successfully predicted to have trade relations between 2008 and 2017 (17 pairs), 14 pairs (82%) of bauxite relations appeared less than two years before being predicted. That is, if two countries traded bauxite for less than two years, they are considered less likely to engage in bauxite trade relations in the future.

(2) In potential trade links, bauxite trade relations are unlikely to occur between the two net exporters.

In Table 3, pairs such as Brazil and Turkey, Hungary and India, and Guyana and Hungary are all net exporters, and bauxite resources are abundant in these countries, so they are unlikely to trade bauxite. At the same time, it is almost unnecessary to exchange bauxite between countries with rich bauxite resources. Therefore, such trade relations are almost impossible to form.

(3) In potential trade links, the possibility of establishing trade relations between the two net importing countries is high. Importing countries represented by the United States, Germany and China may be more likely to establish new trade relations with other countries.

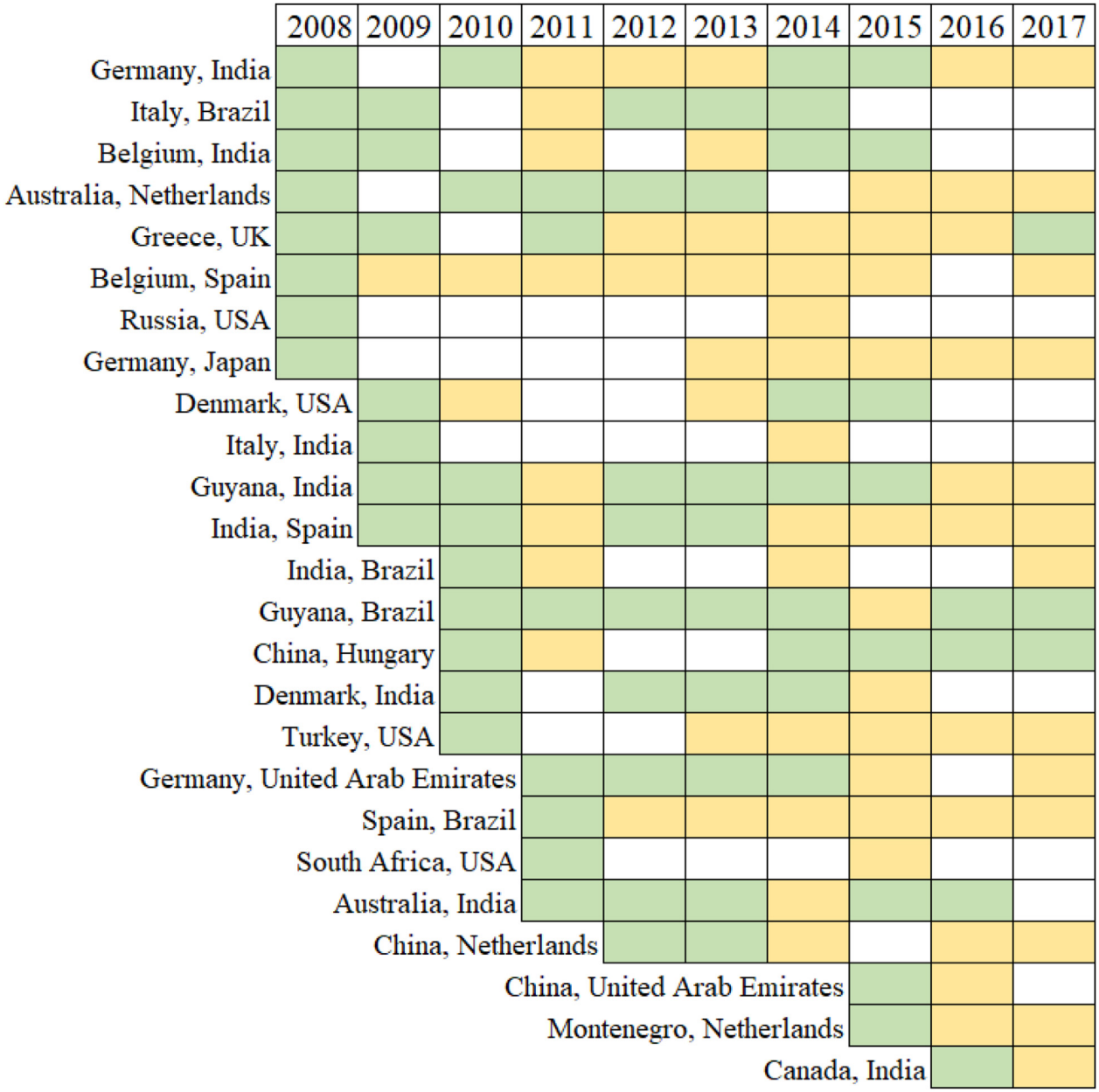


Fig. 5. Country pairs that have been successfully predicted at least once.

Table 2
Top Ten Potential Trade Links in 2017 (the name of the net importing country is marked in bold).

Year	No.	Pair of countries	
2017	1	Guinea	**Netherlands**
2017	2	**Poland**	India
2017	3	Guyana	Brazil
2017	4	**China**	Hungary
2017	5	India	**Ukraine**
2017	6	**Greece**	**UK**
2017	7	Australia	**UK**
2017	8	Hungary	India
2017	9	India	**Slovakia**
2017	10	Guyana	**Belgium**

There are 12 pairs of countries in Fig. 4 that are all net importers. Three of them do not have successful trade relationships, but the remaining nine pairs (72%) were successfully predicted to trade bauxite at least for one year. Among the successfully predicted pairs, the United States (3 pairs), Germany (3 pairs), and China (2 pairs) appeared as one of the trading partners. It can therefore be concluded that if both trading countries are net importers and one of them is the United States, Germany or China, their chances of establishing a trading partnership will increase.

The United States, Germany and China are the world's largest importers of bauxite. For example, before 2014, China's bauxite trading partners were mainly Indonesia and Australia. However, due to Indonesia banning the export of bauxite ore in 2014, the global bauxite pattern underwent significant changes, and China's import channels gradually became more diversified. To prevent their own imports from being affected by the external environment and policies, major import countries began to look for a wider range of cooperative relations, which to a certain extent explains the reasons why these three countries are more likely to establish trade relations with other countries.

(4) In potential trade links, a trade relationship between net importing

Table 3
Countries that have not been successfully predicted in the top ten potential trading countries (the name of the net importing country is marked in bold).

Country A	Country B	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
China	Guyana	P	P								
Austria	**USA**	P									
Ukraine	**USA**		P		P						
Greece	India		P		P						
Denmark	Guyana			P	P	P	P				
Brazil	Turkey						T	P			
Guinea	**Netherlands**								P		
Canada	**Germany**	T	T	T	T	T	T		P	P	P
Hungary	India									P	P
Turkey	**UK**									P	
Hungary	**USA**									P	
Guyana	Hungary									P	
Poland	India									P	P
India	**Slovakia**										P
India	**Ukraine**									T	P
Australia	**UK**	T						T		T	P
Guyana	**Belgium**	T						T			P

Table 4
Role division of potential trading countries from 2008 to 2017.

No.	Country	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Final role
1	Australia	E	E	E	E	E	E	E	E	E	E	E
2	Brazil	E	E	E	E	E	E	E	E	E	E	E
3	Guyana	E	E	E	E	E	E	E	E	E	E	E
4	Montenegro	E	E	E	E	E	E	E	E	E	E	E
5	Turkey	E	E	E	E	E	E	E	E	E	E	E
6	Guinea	E	0	0	0	0	E	E	E	0	0	E
7	Greece	E	E	E	E	E	E	I	I	I	I	I
8	India	E	E	I	E	E	E	E	E	E	E	E
9	Italy	I	I	E	E	E	E	E	E	I	I	I
10	Hungary	I	I	I	I	I	I	E	E	E	E	E
11	Belgium	I	E	I	I	I	I	I	E	E	I	I
12	South Africa	I	I	E	I	I	I	I	I	I	I	I
13	Austria	I	I	I	I	E	E	I	I	I	I	I
14	Denmark	I	I	I	I	E	I	I	I	I	I	I
15	Netherlands	I	I	I	I	I	E	I	I	I	I	I
16	United Arab Emirates	I	I	I	I	I	I	I	I	I	0	I
17	Canada	I	I	I	I	I	I	I	I	I	I	I
18	China	I	I	I	I	I	I	I	I	I	I	I
19	Germany	I	I	I	I	I	I	I	I	I	I	I
20	Japan	I	I	I	I	I	I	I	I	I	I	I
21	Poland	I	I	I	I	I	I	I	I	I	I	I
22	Russian	I	I	I	I	I	I	I	I	I	I	I
23	Slovakia	I	I	I	I	I	I	I	I	I	I	I
24	Spain	I	I	I	I	I	I	I	I	I	I	I
25	Ukraine	I	I	I	I	I	I	I	I	I	I	I
26	UK	I	I	I	I	I	I	I	I	I	I	I
27	USA	I	I	I	I	I	I	I	I	I	I	I

countries and net exporting countries will be realized in the next few years.

Looking at Fig. 4, one can see a lack of data after 2017; apart from the 2017 predicted links, there are 19 pairs of countries that consist of a net importing country and a net exporting country. A total of 12 pairs (63%) of these trade links were successfully predicted at least once. This shows that trade relations between countries playing different trade roles are more likely to be established, which is consistent with common sense.

4. Conclusions and policy implications

As an important strategic and non-renewable resource, bauxite plays an important role in the economic development of various countries. Recently, with the recovery of the world economy, the global aluminium market is developing rapidly, which has stimulated the growth in demand for bauxite resources. However, due to the uncertainty of international trade relations, this paper uses the emerging method of complex network theory and link prediction to explore the potential bauxite trade links. Based on the results, the following conclusions and recommendations are made.

(1) Among the top ten potential trade links, countries participating in the bauxite trade are more inclined to maintain existing trade relations with previous trading partners. The role of a country also influences the formation of trade relations. For example, it is almost impossible to trade bauxite between two net exporters. If one of the

Table 5
Potential links for bauxite (pink represents a net exporter, grey represents a net importer, T represents a bauxite trade in the corresponding year, and P represents a bauxite trade prediction in the corresponding year.).

No.	Country A	Country B	2013	2014	2015	2016	2017
1	Italy	Brazil	P	P			
2	Belgium	India	T	P	P		
3	Denmark	USA	T	P	P		
4	China	Hungary		P	P	P	P
5	Denmark	Guyana	P				
6	Brazil	Turkey	T	P			
7	Guinea	Netherlands			P		
8	Canada	Germany	T		P	P	P
9	Hungary	India				P	P
10	Turkey	UK				P	
11	Hungary	USA				P	
12	Guyana	Hungary				P	
13	Poland	India				P	P
14	India	Ukraine				T	P
15	Australia	UK		T		T	P
16	India	Slovakia					P
17	Guyana	Belgium		T			P

two bauxite net importing countries is the United States, Germany or China, the possibility of trading bauxite between them will be greatly increased. Moreover, trade relations between bauxite importers and bauxite exporters are most likely to occur.

In short, it is possible to initially search for potential bauxite trade based on the number of national trading partners and then further evaluate potential trade links based on the discovered trade rules as well as the policies on bauxite.

(2) Table 5 lists the countries that appeared in the top ten potential trade links but have not actually traded bauxite after being predicted from 2013 to 2017. These 17 pairs of countries are potential bauxite trading partners, and then the most probable bauxite trade links will be sought. It should be noted that the purpose of this paper is not to determine the exact time for establishing trade relations but rather to provide a reference for the government to find new trading partners based on the topological attributes of each country.

Combining the trade rules found in this paper, we predict that Denmark and the United States (No. 3), China and Hungary (No. 4), Guinea and the Netherlands (No. 7), Hungary and the United States (No. 11), Australia and the United Kingdom (No. 15) are most likely to establish bauxite trade relationships within five to six years. In terms of national roles, they are composed of net importers and net exporters. From the perspective of policy factors, the United States is planning to expand the capacity of the aluminium industry and will import a large amount of bauxite. The diversification of its bauxite source needs to be improved, so the potential trade relationship with the United States will be established quickly. China's bauxite resources are relatively scarce. In addition, in 2012, Indonesia announced that it will not export bauxite in the form of raw materials. To avoid an increase in bauxite prices and thus affect the efficiency of enterprises, China will certainly expand the sources of bauxite resources. Guinea has vigorously developed its mining economy in recent years. The local government has issued a notice stating that in order to strengthen its leading position in bauxite production, it will further expand the production of bauxite and increase it by two a factor of two by 2020. This will accelerate the creation of its potential trade relations. Moreover, Australia is one of the countries that has the most abundant bauxite resources, so it is also a country that seeks diversification of trading partners. However, Brazil and Turkey (No. 6), Hungary and India (No. 7), and Guyana and Hungary (No. 12) are the least likely to have bauxite trade relations because they are all bauxite exporters.

(3) From a policy perspective, the practical significance of this paper is mainly reflected in two aspects. On the one hand, in the face of the breakdown of trade relations or increased diversity of trading partners, countries can seek new partners in advance through this research. On the other hand, bauxite trading countries can make preliminary preparations to adjust their trading strategies with reference to the predictions of the above potential trade links because a country's exports or imports may be affected by the new trade relationships of its important partners. For example, for bauxite-importing countries, if one of the country's major bauxite trading partners establishes a new trade relationship and exports a large amount of bauxite to another importing country, the importing country's imports may be reduced, and its normal use of bauxite may be threatened. Moreover, the more bauxite trading partners a country has, the more likely it is to establish new trade relationships with other countries. In this approach, countries with less trade volume are as important as countries with more trade volume. Therefore, even if the trade volume is small, countries should try to establish bauxite trade relations with more partners. Doing so will not only improve trade security but also expand the influence of the bauxite international trade market.

This paper studies international bauxite trade relationships from a new perspective of link prediction and finds potential trade links according to the topological attributes of each country. However, the creation of bauxite international trade relations may be affected by many aspects. Therefore, in the future, this paper will further analyses the international trade relationship of bauxite, and make more accurate predictions and more in-depth evaluation of potential trade links by combining trade volume and trade direction as well as other factors.

Acknowledgements

This research was funded by the National Social Science Fund of China (Grant No. 17BGL202).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.resourpol.2019.101417.

References

Aaron, C., Cristopher, M., Newman, M.E.J., 2008. Hierarchical structure and the prediction of missing links in networks. Nature 453 (7191), 98.
Ahmad, M.A., et al., 2012. Love All, Trust a Few: Link Prediction for Trust and Psycho-Social Factors in MMOs.
Almansoori, W., et al., 2011. Link prediction and classification in social networks and its application in healthcare. In: IEEE International Conference on Information Reuse & Integration.
Berlusconi, G., et al., 2016. Link prediction in criminal networks: a tool for criminal intelligence analysis. PLoS One 11 (4), e0154244.
Bird, M.I., Chivas, A.R., Andrew, A.S., 1989. A stable-isotope study of lateritic bauxites. Geochem. Cosmochim. Acta 53 (6), 1411–1420.
Chuan-Yang, Y., et al., 2006. Decoupling process for better synchronizability on scale-free networks. Phys. Rev. E - Stat. Nonlinear Soft Matter Phys. 74 (2), 047102.
Duan, W.Q., 2008. Estimating trade flow based on network topology. Phys. Stat. Mech. Appl. 387 (2), 519–527.
Fawcett, T., 2005. An introduction to ROC analysis. Pattern Recogn. Lett. 27 (8), 861–874.
Feng, S., et al., 2017. Who Will Build New Trade Relations? Finding Potential Relations in International Liquefied Natural Gas Trade. Energy, pp. 141.
Foschi, R., Riccaboni, M., Schiavo, S., 2013. Missing links in multiple trade networks. In:

International Conference on Signal-Image Technology & Internet-Based Systems.
Gang, L., Müller, D.B., 2013. Mapping the global journey of anthropogenic aluminum: a trade-linked multilevel material flow analysis. Environ. Sci. Technol. 47 (20), 11873–11881.
Guan, Q., et al., 2016. Estimating potential trade links in the international crude oil trade: a link prediction approach. Energy 102, 406–415.
Guo-Qing, Z., Di, W., Guo-Jie, L., 2007. Enhancing the transmission efficiency by edge deletion in scale-free networks. Phys. Rev. E - Stat. Nonlinear Soft Matter Phys. 76 (1 Pt 2), 017101.
Ji, Q., Zhang, H.Y., Fan, Y., 2014. Identification of global oil trade patterns: an empirical research based on complex network theory. Energy Convers. Manag. 85 (9), 856–865.
Kong, Q.J., et al., 2013. UTN-Model-Based traffic flow prediction for parallel-transportation management systems. IEEE Trans. Intell. Transp. Syst. 14 (3), 1541–1547.
Liben-Nowell, D., Kleinberg, J., 2003. The Link Prediction Problem for Social Networks.
Lü, L., Zhou, T., 2011. Link prediction in complex networks: a survey. Phys. Stat. Mech. Appl. 390 (6), 1150–1170.
Petter, H., et al., 2002. Attack vulnerability of complex networks. Phys. Rev. E - Stat. Nonlinear Soft Matter Phys. 65 (2), 056109.
Sherkat, E., Rahgozar, M., Asadpour, M., 2015. Structural link prediction based on ant colony approach in social networks. Phys. Stat. Mech. Appl. 419, 80–94.
Shi, F., Foster, J.G., Evans, J.A., 2015. Weaving the fabric of science: dynamic network models of science's unfolding structure. Soc. Network. 43, 73–85.
Shi, C., et al., 2018. Study on the Evolution Characteristics of International Bauxite Trade from the Perspective of Complex Network. China Mining Magazine.
Terekhov, I., Evans, A., Gollnick, V., 2015. Forecasting a global air passenger demand network using weighted similarity-based algorithms. In: Atrs World Conference.
Trattner, C., et al., 2014. Who Will Trade with Whom? Predicting Buyer-Seller Interactions in Online Trading Platforms through Social Networks.
Tuninetti, M., et al., 2016. To trade or not to trade: link prediction in the virtual water network. Adv. Water Resour. 110.
Vidmer, A., et al., 2015. Prediction in complex systems: the case of the international trade network. Phys. Stat. Mech. Appl. 436, 188–199.
Wehr, J.B., Fulton, I., Menzies, N.W., 2006. Revegetation strategies for bauxite refinery residue: a case study of alcan gove in northern territory, Australia. Environ. Manag. 37 (3), 297–306.
Yalçın, N., Sevinç, V., 2000. Utilization of bauxite waste in ceramic glazes. Ceram. Int. 26 (5), 485–493.
Zhou, et al., 2009. Predicting missing links via local information. Eur. Phys. J. B 71 (4), 623–630.