Energy 102 (2016) 406–415

Contents lists available at ScienceDirect

Energy

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

Estimating potential trade links in the international crude oil trade: A link prediction approach

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ARTICLE INFO

Article history:
Received 22 May 2015
Received in revised form
14 October 2015
Accepted 16 February 2016
Available online 12 March 2016

Keywords:
Trade links
Crude oil
International trade
Link prediction

ABSTRACT

Estimating potential trade links is essential for exploring the information implied by international crude oil trade data, which contain obvious trade links among countries. In addition, it is important for governments to assess the evolution trend of international crude oil trade in order to avoid trade risk. This study introduces the link prediction approach to explore potential trade links from the perspective of relations based on the topological attributes of countries. We take the number of common trade partners for each country pair as the potential linking motivation. Based on this, we confirm this as a general feature for most existing trade links and thereby describe the real distribution of trade relations. Furthermore, our study analyzes the practical meanings of explored potential trade links with considerations of countries' crude oil trade roles. We find that the number of common trade partners is indeed one of the structural linking motivations in international crude oil trade. It can not only represent the possibility of trading relations, but also reflect the competition among countries. By using this evaluation index, we then estimate potential trade partners combined with countries' crude oil trade roles and provide suggestions for governments about future trading strategies.

1. Introduction

It is clear that oil-rich countries trade with countries that have poor oil reserves, while countries with a lack of oil expand their crude oil trade relationships with both oil-rich and oil-poor countries in order to satisfy their oil requirements and safeguard their energy security. However, *potential* trade links also exist among countries. Indeed, estimating these potential trade links is essential for researchers to explore crude oil trade relations among countries [1,2] that are not explained by the available data [3,4]. Although countries may not obviously trade, the trade patterns and interactions between each pair of countries form links, which may encourage them to trade in the future. Thus, estimating potential trade links allows researchers to evaluate implied trade links, which can easily be neglected. Further, this endeavor is meaningful for governments because they are eager to increase their understanding of international crude oil trade in order to avoid trade risk [5]. Based on the foregoing, this study explores potential trade links from a fresh perspective based on international crude oil trade patterns.

Most previous studies focus on analyzing the structure and evolution of international crude oil trade patterns [6]. Some expand their descriptions of trade relations to include competition [4,7], while others examine the reactions of countries when facing crises or global events [8]. In addition, some authors have attempted to predict trade flows for known trade links by using country-level variables such as the gross domestic product (GDP) or currency union [1,9], which cannot be derived from trade patterns. These studies hence focus on the exploration or assessment of obvious, but not potential, trade links. However, the expansion of trade networks has continued to influence international trade relationships and even promote the construction of new trade links.

To estimate potential trade links, we use the link prediction approach [10], which is based on the complex network theory [11], to provide a new insight into these global trade relationships [12,13]. Prior studies about link prediction are mainly about conducting or improving physical models [16–19]. For example, these models have been applied to social networks which aim to make

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http://dx.doi.org/10.1016/j.energy.2016.02.099
0360-5442/

better friendship recommendations [20], biological networks which aim to explore unknown neural interactions [21], and US air transportation networks which aim to estimate the possible construction of airlines [10]. These networks have thus been used to measure algorithm precision [22], which confirms that it is useful for estimating potential network links. Thus, we apply link prediction to estimate potential trade links in international crude oil trade. Analyzing the observed network structures and statistical properties of selected countries allows us to investigate the potential motivation behind the construction of existing trade links [14,15].

In this study, we estimate potential trade links based on real trade patterns in order to provide a fresh perspective on trade relations among countries. In order to describe the linking motivation of international crude oil trade, we define an evaluation index calculated by using the topological attributes of the observed countries. We then use a test index to examine the ability of our evaluation index to estimate the distribution of real trade links. Furthermore, our research compares the potential trade links proposed by our estimation results based on the tested evaluation index with real trade links to assess the evolution of these potential ones. Then, to explore the practical meanings of potential trade links which provide more clear and instructive information, we divide involved countries into different crude oil trade roles which synthetically consider the crude oil importation, exportation and proved reserves respectively. Through the division of comparisons and countries' crude oil trade roles, we finally obtain further practical understanding of these trade links. From the perspective of the consideration of the topological attributes of each pair of countries, our work not only estimates relationships that have potential trade links formed by real trade patterns, but may also allow us to predict future new trade cooperation or competition between certain pairs of countries.

The remainder of this paper is organized as follows. The next section introduces the data source and algorithm steps of link prediction. Section 3 confirms the feasibility of the proposed evaluation index and analyzes the empirical results. Section 4 discusses, including making estimations about future trade relations. Section 5 concludes.

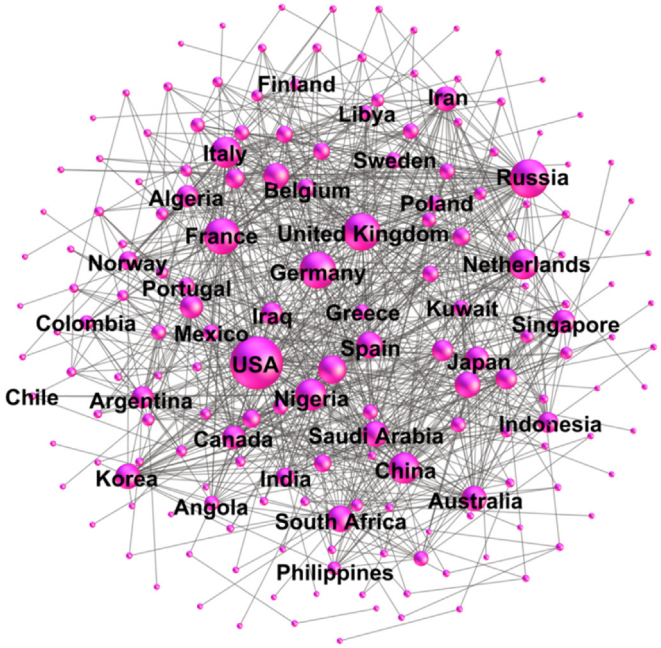

Fig. 1. Countries and their relations in international crude oil trade in 2000.

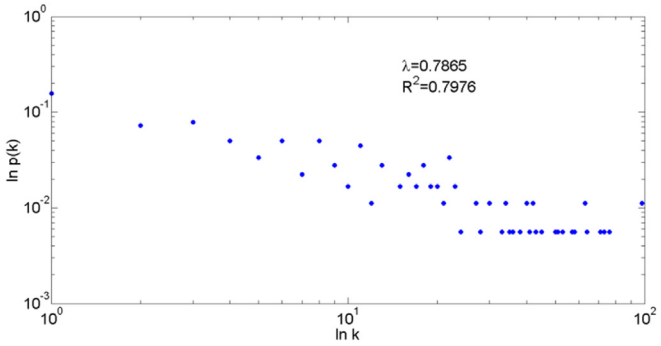

Fig. 2. The power-low distribution of international crude oil trade in 2013.

2. Data and methodology

2.1. Data

This study derived data on international crude oil trade (HS Code 270900) from UN Comtrade, annually from 2000 to 2013. We cleaned repeated data and labeled existing trade relationships for each pair of directly related countries in each year, without any consideration of trade flow and volume. Existing trade relations are defined as those with a clear record of trade value or weight. We used the trade relationships among countries in 1 year as the data-processing unit. As a result, we obtained 13 data units. Fig. 1 shows the pairs of countries and their existing trade relations in the international crude oil trade in 2000.

Taking the 2013 data unit as an example (Fig. 2), international crude oil trade is a typical network with the characteristic of power-low distribution, $p(k) \sim k^{-\lambda}$, where k is the amount of direct trade partners for each country; p(k) is the frequency of each k; R^2 is the goodness-of-fit; λ is the degree of power-low distribution, which means that smaller countries hold the bulk of oil resources.

2.2. Methodology

2.2.1. Link prediction model

Based on the structural properties of each pair of countries, we applied the link prediction approach to the annual data on international crude oil trade. The link prediction algorithm presented in this subsection has been described in detail by previous link prediction papers [10,12,13]. We herein only show the steps briefly combined with the characteristics of international crude oil trade. The variables used to deal with each data unit are shown in Table 1.

Given the status of international crude oil trade, we show the algorithm in the following five steps:

(1) Define an evaluation index based on the structural properties of countries

We use common neighbor (CN) as the evaluation index. Under the CN approach, the higher the score of a link, the higher is its construction possibility. CN is generally considered to be the most effective index for evaluating the linking probability for most types of research objects [10,13]. In particular, for those networks apparently characterized by a power-low distribution such as international crude oil trade networks, CN always has better performance than most other complicated evaluation indexes. Thus, it is reliable to use this index to describe the construction of trade links.

Table 1
Variables used to deal with each data unit.

Variable	Description
N	The number of countries
M	The number of existing trade links
U	The set of all possible links based on N nodes, U=N(N−1)/2
V	The set of countries
E	The set of existing trade links
E^T	The set of training links, $E-E^P$
E^P	The set of test links, 10% of E, generated randomly E^T
s_{xy}	The score evaluated on each link in $U-E^T=(U-E)+E^P$, according to selected indexes based on the statistical properties of two directly related countries

The index based on CNs is defined as follows:

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

where x and y are the two countries connected by a trade link. $\Gamma(x)$ is the set of countries connected with x directly, meaning that $|\Gamma(x)\cap\Gamma(y)|$ represents their number of common direct trade partners. Based on this definition of the score, Fig. 3 presents a simple example of the algorithm processes.

(2) Divide existing trade links into 90% training links and 10% test links

In order to examine the precision of CN to describe real trade links, we need to select known trade links as samples to compare with unknown trade links. Thus, we randomly choose 10% of existing trade links as test links, E^P, and the remainder as training links, E^T.

$$\left|E^P\right| = 10\%|E| \text{ and } E^P + E^T = E \tag{2}$$

(3) Calculate the CN score for test and unknown trade links

To compare the feature of CN for test and unknown links, we then calculate their index values according to the definition of CN. Specifically, we calculate each link's number of CNs based on the topological attributes of its two directly connected nodes (i.e., countries). The topological attributes of these nodes represent the structural features of these countries under the observed trade pattern.

(4) Rank test and unknown links based on their index values and analyze their distributions

The definition of CN shows that if a trade link has a higher index value, it has a higher possibility of being linked. Thus, generally, we need to rank the value from the maximum to the minimum. If most test links are ranked higher than most unknown links, CN is shown to be one a common structural feature of most existing trade links. Hence, this index can be used to estimate potential trade links.

(5) Quantify the estimation accuracy of the evaluation index

We use a test index to quantify the distribution of test links. Because we have ranked test links and unknown links based on their index values from the maximum to the minimum, the ideal condition is that most top ranking links are test links.

Widely used indexes include the Area Under the Receiver Operating Characteristic Curve and Precision and Ranking Score (RankS) [12]. To consider the whole ranking situation and avoid producing random numbers twice, we choose RankS as the test index. Its definition

$$\text{RankS} = 1\Big/\left|E^P\right|\sum_{i\in E^p} r_i\Big/\left|U-E^T\right| \tag{3}$$

where r_i is the rank of test link i. Thus, the lower RankS, the higher the precision is.

For international crude oil trade, if most test links have a higher index value than the others, it means that this index, the number of common direct trade partners, has the ability to describe the distribution of links in real trade patterns. As a result, CN can affect the general features of most existing trade relationships. This index also shows that if a pair of countries has a high number of identical trade cooperation objects, they would have more likelihood of constructing trade relations with each other. Similar to friendships in social networks, countries that are close and have strong political and economic relationships tend to trade with each other, becoming stable trade partners. As a result, this index is also meaningful for international trade.

Furthermore, link prediction can be widely used in various international trade networks. By examining the viability of the proposed evaluation index, which has been proven to be effective for describing real trade links [10,20], researchers can use it to estimate potential trade links.

2.2.2. The analysis model involving oil sectors

The exploration of potential trade links provides a statistical perspective to analyze the trade relationships across the world. However, the oil sectors among countries are different. For

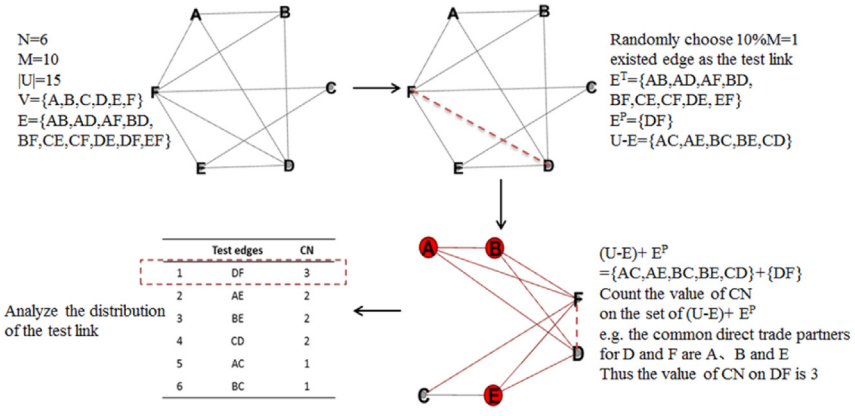

Fig. 3. Algorithm processes applied to a model with six countries and 10 trade links.

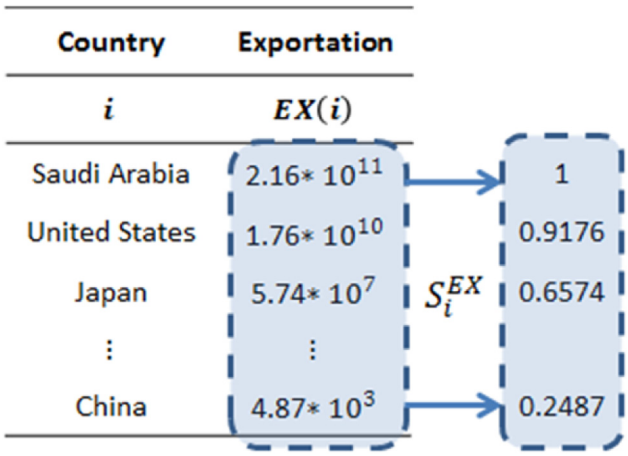

Fig. 4. A simple example of the mapping rule.

example, Japan is the country with low oil reserves and tends to import crude oil; Saudi Arabia is the country with high oil reserves and tends to export crude oil; United States is the country with certain amount of oil reserves and has both high amount of oil importation and exportation. Thus, countries with different oil sectors make trade links have various practical meanings, and the exploration of them is helpful to distinguish potential trade links better.

To explore practical meanings of potential trade links, we set a crude oil trade and reserves index (COT&R-I for short) to evaluate the trade role for each country comprehensively. COT&R-I considers the oil sectors, including importation, exportation and proved reserves for each country. We define I as the set of countries. For $\forall i \in$ I, EX(i) represents the direct importation for the country i (the unit is kg); IM(i) represents the direct exportation for the country i (the unit is kg); PR(i) represents the crude oil proved reserves for the country i (the unit is billion barrels). Thus EX(i), IM(i) and PR(i) are sub-index values for the country i.

If the order of magnitude for one sub-index is always relative higher than other sub-indexes, it will affect the precision of comprehensive evaluation results. To solve this problem, we set the mapping rule according to the data, which is shown in Fig. 4. If EX(i) can be represented as $n*10^m$, where m is the integer that represents the order of magnitude ($0 < m < 11$), and n is the real coefficient ($0 \le n < 10$), then the score of the sub-index EX(i) is defined as:

$$S_i^{EX} = \begin{cases} (m-1)*0.1 + n*0.01, & 0 \le EX(i) < 10^{11} \\ 1, & EX(i) \ge 10^{11} \end{cases} \quad (4)$$

The definition of scores for IM(i) and PR(i) are same as EX(i)'s. The value of COT&R-I is defined as:

$$S_i = S_i^{EX} - S_i^{IM} + S_i^{PR} \quad (5)$$

As a result, the country i with lower value of COT&R-I tends to be an importer; with higher values tends to be an exporter; with medium value tends to be the trade role of both importer and exporter.

3. Results and analysis

3.1. Distribution of test links

In order to explore potential trade links, we need to know the relevance between the attributes of countries and their trade relationships (i.e., the common feature for most existing links). To analyze the potential rule of the number of common trade partners for existing trade relationships, in this part, we analyze the distribution of test links in three types of distributions. These links are those including test links and inexistent links, and we rank them from maximum to minimum according to their score.

The first type of statistical distribution shows the distribution of test links according to their score-based rankings. Fig. 5 indicates the features for most test links from 2000 to 2013. If the block in a ranking is blue, it means that a test link is at this position. Regardless of the year, it is apparent that almost all test links are high ranking. Although some test links appear at the bottom of the rankings, the whole distribution proves that a great proportion have a higher number of common trade neighbors compared with links that do not really carry out real trade in that year. This result proves that most linked pairs of countries have a high number of crude oil trade partners.

Fig. 6 includes another two types of statistical distributions in 2000 and 2013 that consider the number and percentage of test links for each different score value, respectively. As shown in Fig. 6, in spite of the small differences in the scale of trade, there are many common characteristics in 2000 and 2013. The general trends show that the characteristics for these two distributions are contrary. First, the number of test links for each score value is decreasing. At the beginning, the trend declines a little with some fluctuation when the score value is below 7 in 2000 and 12 in 2013, before dropping to a relatively low level. This finding means that not all trade relationships have a high number of common trade partners (most have about seven trade partners in 2000 and about 12 in 2013), which confirms the expansion of trade cooperation for most countries over time. However, despite some instability, the general trend in the latter distribution is increasing. This finding means that the percentage of test links grows as the CN value increases, which confirms that the more they have a number of common trade partners, the more they may trade.

Because our test links are randomly selected from real trade links, this sample is able to reflect the features of all existing relations. As a result, these features confirm, firstly, that most existing trade relationships have a similar number of common trade partners and, secondly, that links with a high number of this score value have more possibility of being existing ones. Thirdly, countries tend to construct steady trade relationships with a certain number of partners to guarantee low risk of policies and economic. However, if a pair of countries has a high number of common trade partners, they would have more possibility of constructing trade relationships. Indeed, we find a one-way relation between the number of common trade partners and possibility to trading. This potential principle for the construction of trade relations directs us to measure the trade links from this structural perspective.

3.2. Index validation

To validate the evaluation index, we use the test index, RankS, to measure the ranking results. Specifically, we evaluate whether the number of common trade partners can describe the real distribution trade relationships. We calculate RankS based on the ranking of CN values from 2000 to 2013 (see Fig. 7).

Fig. 7 shows that the ranking score during this period is between 0.1 and 0.16, which was thought to be effective. Compared with 0.18, which is the RankS value for the Chinese airline network based on the CN index [12], which was thought to be valid for describing the airline relationships between regions, our data are lower, which indicates higher precision.

Because test links are chosen randomly, RankS is relatively affected. As a result, although the trend of RankS is relatively variable, the difference is not exaggerated, which proves that link

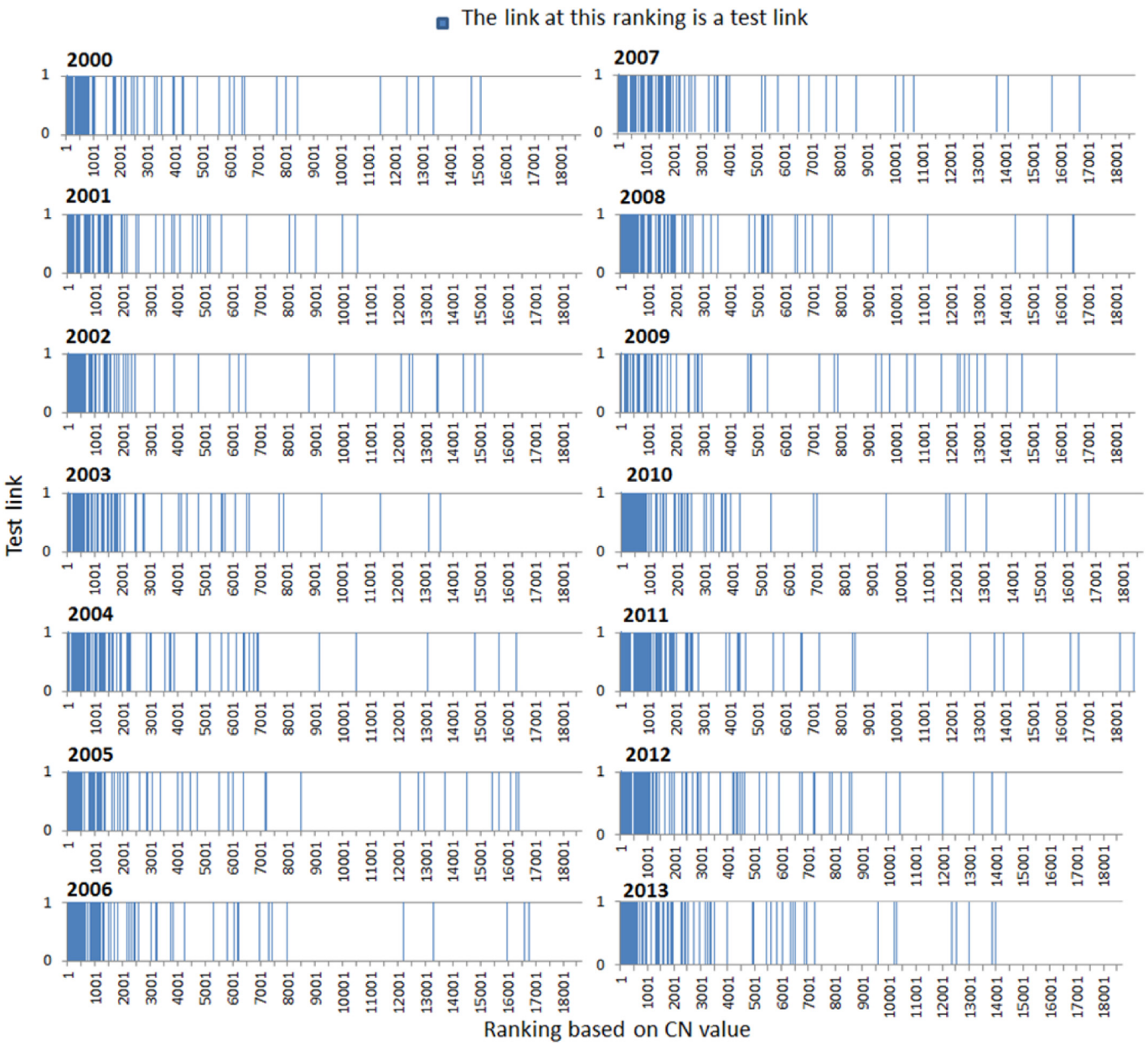

Fig. 5. Rankings of each test edge according to their CN value from maximum to minimum.

prediction is concerned with the topological features but not the scale of the research target. As a result, the validation of the index proves that CN can be applied to trade networks and is effective at predicting trade links.

3.3. Comparison of potential with real trade links

Based on the general feature among most test links, we provide precise information on potential trade links according to their index value. From the yearly rankings, we see that some of the links, although within the top 10, are not real trade relationships. Hence, we can state that these pairs have potential trade links from the perspective of their trading possibility. Table 2 shows the top 10 rankings in 2000 as an example. The table shows that three pairs of countries (Japan and Korea, Nigeria and Saudi Arabia, China and France) have a high number of trade partners, but no trade relationships with each other in 2000. However, from the perspective of their rankings based on CN value, they have potential trade links owing to their topological properties. In summary, although they have no trade relations in 2000, all the trade patterns suggest that each pair interacts with each other, encouraging them to trade.

Next, we compare the prediction results with actual international trade to analyze the evolution of potential trade relations from the perspective of the structural attributes of each pair of countries. First, we examine whether those links with high CN value could really be fulfilled in future years. Second, we explore more trading information from the difference found from the comparison, including those pairs of countries that should trade at a high probability but had not formed trade relations by 2013 and those whose trade relationships have fluctuated.

Fig. 8 displays all potential trade links from 2000 to 2013. We focus on the pairs of countries from the top 10 that did not trade in that particular year. The light green blocks represent the year in which they are in the top 10 rankings and the numbers represents

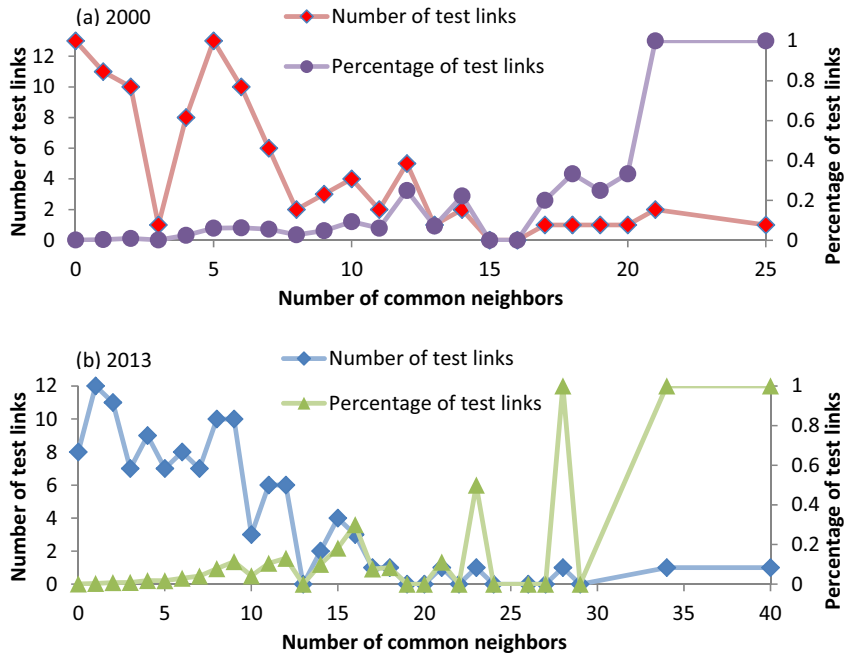

Fig. 6. Number and percentage of test edges for each CN value.

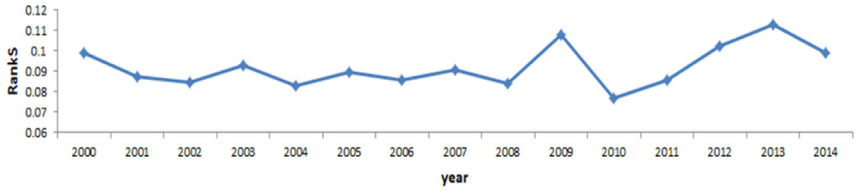

Fig. 7. RankS based on the ranking of CN value from 2000 to 2013.

the times that this pair is in top 10. If there is no number in the light green blocks, this pair appears just once in top 10 from 2000 to 2013. The dark green blocks show the year in which the pair of countries firstly becomes real trading partners after the most recent year that they have no trade relation. This figure confirms that most potential trade links are fulfilled in their future years, although the complex status of international crude oil trade complicates the period of implementation. To obtain further findings from the results, we group them into three categories.

The first category is those pairs that fulfill their potential trade links in recent years, such as Japan and Korea in 2000, France and the Netherlands in 2001, and Korea and the United States in 2005. They construct their trade relationships the year immediately after they first enter the top 10 pairs. In other words, these countries trade with each other rapidly once they reach almost the highest number of common trading partners compared with other pairs. This result also demonstrates the influence of a high number of common trade partners on the establishment of trade relationships and thereby validates the perspective presented herein.

The second category is those pairs whose potential trade links are not fulfilled rapidly, but whose trade will begin within five years, such as China and France in 2000, Italy and the United States in 2002, and France and the United States in 2007. This situation is accompanied with fluctuation in two respects. First, the rankings of these pairs change in this period. Second, trade relations appear and then disappear between certain pairs of countries. For example, the pair of China and France presents these two characteristics. This category proves that although the appearance of trade links is not positive, they have potential trade links from the perspective of their shared structural attributes.

Table 2
Top 10 pairs of countries based on CN value in 2000.

Pairs of countries		CN value	Test link
France	Germany	25	True
France	Italy	21	True
France	United States	21	True
Italy	United States	20	True
Japan	Rep. of Korea	20	False
Nigeria	Saudi Arabia	20	False
China	France	19	False
France	Netherlands	19	True
Germany	Spain	19	False
Iran	Saudi Arabia	19	False

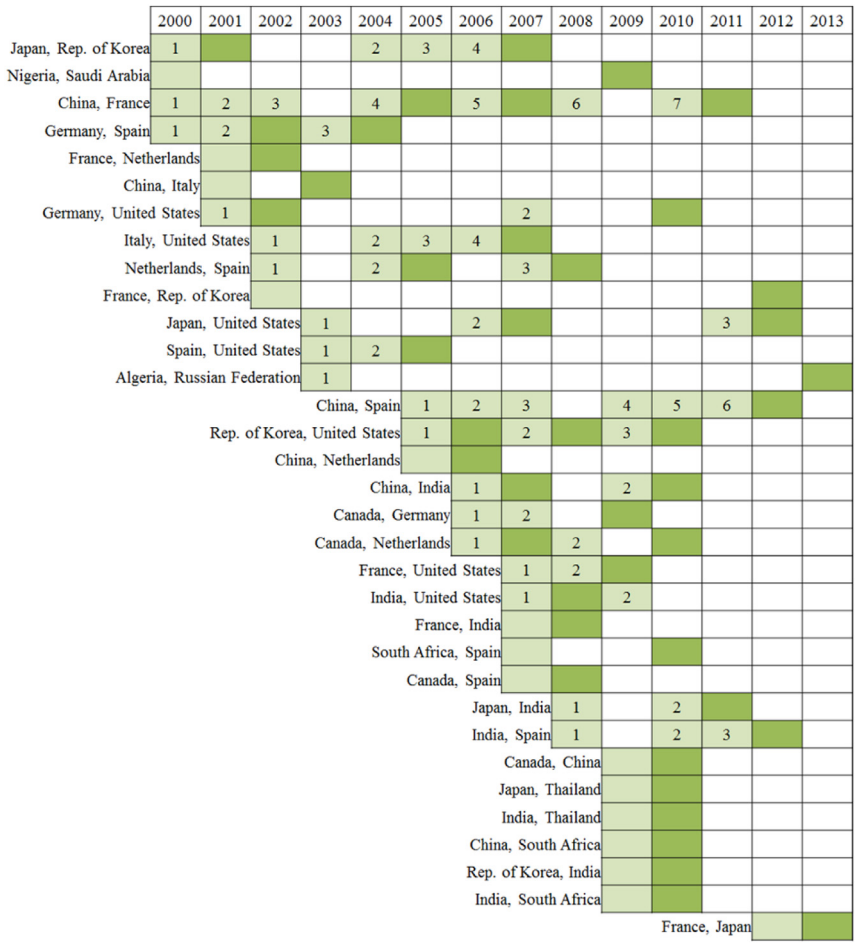

Fig. 8. Pairs of countries with unknown trade links (rankings in the top 10).

The last category includes those pairs that have a high possibility of trading but cooperate a long time later (or even have no trade relationship by 2013; see Table 3). This result shows the marked difference compared with real trade, allowing us recognize country pairs that may begin international crude oil trade in the long-term and reflecting reality partially. Table 3 shows that their rankings are always highly unstable. In particular, the first three pairs of countries that trade after many years are not in the top 10 for long before they start trading. Other pairs of countries that have no crude oil trade cooperation until 2013 also show mixed ranking trends.

However, these countries share some common features. In Table 3, the two country pairs labeled in green both belong to the organization of petroleum exporting countries (OPEC), the three pairs labeled in yellow are between Russia and one OPEC country, and the pair labeled in blue is between two oil-rich non-OPECs, Azerbaijan and Russia. This finding confirms that countries with abundant oil resources export a large quantity of crude oil, leading to a high number of shared trade partners that have no need to exchange this commodity with each other. However, from the perspective of the linking principle, their number of common trade partners means they have potential (hidden) international crude oil trade links. For example, even though both Nigeria and Saudi Arabia are oil-rich countries, they traded in 2009, which confirms the possibilities for these types of country pairs to exist. Meanwhile, the other two pairs with no color are potential trade partners without yet showing real cooperation. Even though the probability of trading in reality seems to be low, the trading possibility from our perspective is high, as their cooperation would aggregate the imbalance between supply and demand. As a result, although we cannot clearly assess when relations might begin, they should not be neglected and they are valuable references for governments.

3.4. Further analysis with considerations of countries' crude oil sectors

3.4.1. The division of crude oil trade roles

To make further analysis of the practical meaning for each potential trade link, according to their values of COT&R-I, we divide related countries into three kinds of trade roles: exporters, importers and both exporters and importers (EX&IM).

From the top 10 potential trade links explored from 2000 to 2013 which are shown in Fig. 8, 17 countries have relative high appearance frequency, which are Japan, India, Italy, Spain, France, United States, Thailand, Netherlands, South Africa, Germany, Rep. of Korea, China, Algeria, Nigeria, Canada, Russian Federation and Saudi Arabia. Whatever the importation, exportation or proved reserves, these countries have apparent differences. Based on the basic data in 2014, we get values of sub-indexes and COT&R-I for these 17 countries, which are shown in Table 4.

According to their values of COT&R-I, we rank these 17 countries from the minimum to the maximum, which is shown in Fig. 9. The division of trade roles and further analysis are as follows.

Table 3
Pairs of countries in the top 10 rankings but with no trade relations a long time later.

Pair of countries		Year joined the top 10				Year of first trade
Nigeria	Saudi Arabia	2000				2009
France	Korea	2002				2012
Algeria	Russia	2003				2013
Iran	Saudi Arabia	2000	2002	2003	2004	-
Russia	Saudi Arabia	2003				-
Nigeria	Russia	2003				-
China	Germany	2005	2010	2011	2012	-
Azerbaijan	Russia	2008	2010	2012		-

(1) Exporters

Canada, Russian Federation, Nigeria, Algeria and Saudi Arabia are exporters. Their COT&R-I values are all above zero, which means that all of them have both high proved crude oil reserves and high exportation.

(2) EX&IMs

United States, Rep. of Korea, Netherlands, Spain, Germany, Thailand, South Africa and Italy can be seen as EX&IMs. Especially, although United States was the world's largest crude oil importer with $3.74*10^{11}$ kg importation, its exportation had been increasing year by year as its development of shale gas, which made it as an more and more important exporter. As a result, United States acts as both importer and exporter. Furthermore, interestingly, other seven countries are all have low proved reserves but relative not low exportation. It approves that these countries tend to exchange crude oil, which make their role of exporter also important.

(3) Importers

France, Japan, India and China are four classical importers with low proved reserves and exportation. Especially for China, it reduced large amount of exportation in 2014, and mostly depended on importation. Objectively, the division result is relatively consistent with the real. As the changes of trade strategies in future years, their trade roles will fluctuate. For example, if United States continuously raises its exportation, it will become an exporter rather than an EX&IM. And China will regain its EX&IM role if it recovers high exportation.

3.4.2. Potential trade links between trade roles

The division of trade roles helps us to make twice comparison of potential trade links. Replaced by their trade roles, we get quantization results, which include trade flows and corresponding trade volumes among exporters, importers and EX&IMs (Table 5).

From Table 5, main trade flows with highest trade volumes are all from exporters. To our surprise, exporters also import high volume of crude oil from those countries with certain amount of

Table 4
Importation, S_i^{IM}, exportation, S_i^{EX}, proved reserves, S_i^{PR} for 17 countries, 2014.

Country	Importation (kg)	S^{IM}	Exportation (kg)	S^{EX}	Proved reserves (Billion barrels)	S^{PR}
China	$1.51*10^{11}$	0.91510	$4.87*10^{03}$	0.24866	$1.85*10^{01}$	0.01850
India	$1.90*10^{11}$	1.00000	$3.70*10^{07}$	0.63700	$0.57*10^{01}$	0.00570
Japan	$1.69*10^{11}$	1.00000	$5.74*10^{07}$	0.65740	$0.05*10^{01}$	0.00054
France	$5.49*10^{10}$	0.95490	$2.14*10^{07}$	0.62140	$0.00*10^{01}$	0.00000
Italy	$7.01*10^{10}$	0.97010	$6.18*10^{08}$	0.76180	$0.06*10^{01}$	0.00060
South Africa	$2.13*10^{10}$	0.92130	$1.65*10^{08}$	0.71650	$0.00*10^{01}$	0.00000
Thailand	$4.14*10^{10}$	0.94140	$5.56*10^{08}$	0.75560	$0.05*10^{01}$	0.00050
Germany	$1.84*10^{10}$	0.91840	$3.29*10^{08}$	0.73290	$0.02*10^{01}$	0.00023
Spain	$6.27*10^{10}$	0.96270	$1.42*10^{09}$	0.81420	$0.02*10^{01}$	0.00015
Netherlands	$4.00*10^{10}$	0.94000	$1.03*10^{09}$	0.81030	$0.03*10^{01}$	0.00030
Rep. of Korea	$4.55*10^{09}$	0.84550	$3.96*10^{08}$	0.73960	$0.00*10^{01}$	0.00000
United States	$3.74*10^{11}$	1.00000	$1.76*10^{10}$	0.91760	$4.85*10^{01}$	0.04850
Canada	$2.92*10^{10}$	0.92920	$1.44*10^{11}$	1.00000	$1.73*10^{02}$	0.11730
Russian Federation	$7.66*10^{08}$	0.77660	$1.30*10^{11}$	1.00000	$1.03*10^{02}$	0.11032
Nigeria	$6.42*10^{04}$	0.36421	$7.04*10^{10}$	0.97040	$3.71*10^{01}$	0.03710
Algeria	$2.00*10^{01}$	0.02000	$1.94*10^{10}$	0.91940	$1.22*10^{01}$	0.01220
Saudi Arabia	$2.00*10^{03}$	0.22000	$2.16*10^{11}$	1.00000	$2.67*10^{02}$	0.12670

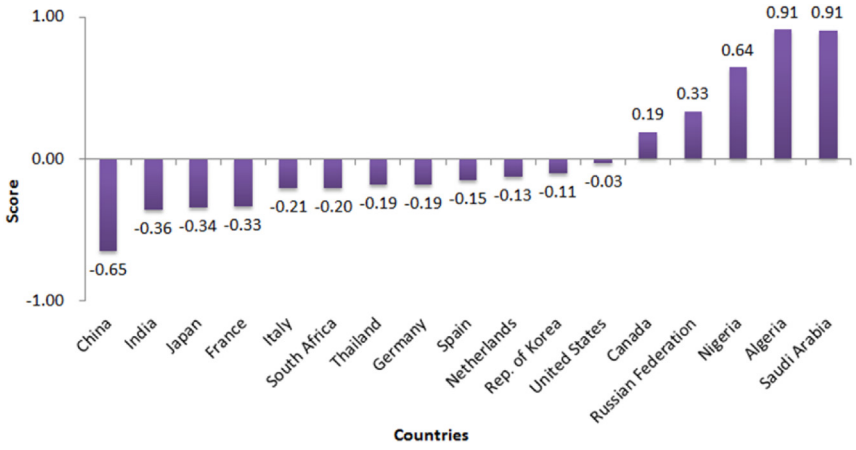

Fig. 9. Values of COT&R-I for 17 countries, 2014.

Table 5
Trade flows and trade volumes among different trade roles,2014.

From	To	Weight(kg)
Exporter	Exporter & Importer	$2.76*10^{11}$
Exporter	Importer	$1.52*10^{11}$
Exporter & Importer	Exporter	$1.63*10^{10}$
Exporter	Exporter	$4.74*10^{09}$
Exporter & Importer	Exporter & Importer	$2.16*10^{09}$
Exporter & Importer	Importer	$1.73*10^{09}$
Importer	Exporter & Importer	$5.99*10^{07}$
Importer	Exporter	$1.36*10^{03}$
Importer	Importer	$2.50*10^{01}$

proved reserves. Furthermore, with highest amount of importation from exporters, EX&IM also exports high amount of crude oil to countries with relative low proved reserves. Last, the exportation for importers is very low.

As a result, if we take the trade flow into account, we can know that a potential trade link with two countries that are exporters or EX&IMs have relative high possibility to be constructed. It is also applicable to trade flows to importers. However, trade links from importers has low possibility to be constructed. Especially, for two importers, their potential trade link tends to represent the relationship of cooperation and competition. For example, because of their importation dependence, Japan and India have many common direct exporters which form high importation competition. So they had high trading possibility in 2008 and 2010. Meanwhile, because of the requirement of energy policies and the need of energy security, these two countries cooperate in 2011. Thus, the potential trade link between importers is more the exchange than the trade of crude oil.

4. Discussion

4.1. The structural linking motivation in international crude oil trade

The structural linking motivation, which is the statistical feature of trade patterns that can be used to estimate potential trade links, is the concentrated reflection of real linking motivations, reflecting the inspiration behind real linkages. The establishment of each trade relationship is affected by several elements, making it challenging to recognize the real linking motivation. However, the whole trade pattern is the structural reflection of the international crude oil trade in the real world, while the topological properties of each involved country contain abundant information on these linking motivations. Thus, this concept is a fresh perspective for exploring the linking motivation from the viewpoint of countries' topological properties in order to measure trade links based on the examined structural linking motivation.

The number of CNs for each pair of countries can be one of the structural linking motivations behind international crude oil trade. Our study confirmed a one-way relation between the number of common trade partners and construction of trade links. A high number of identical trade partners for a pair of countries have a positive influence on the probability of forming a trade relation, although not all existing trade relationships agree with this principle. Because of the importance and imbalance of crude oil, countries tend to trade this commodity with reliable and familiar countries, which are also always the trade partners of countries' direct trade neighbors, forming three-way relations.

Countries with different crude oil trade roles make the links among them have distinguished practical meanings. Part of potential trade links are with high possibility to be constructed, like links between exporters and EX&IMs or between exporters and importers. Another part is those with competition promoted by the trade pattern, like those between two importers. This pressure makes the possibility of trade cooperation low, except the needs to exchange crude oil because of policies or energy security.

Thus, for crude oil, we can also estimate potential trade links based on the number of common trade partners of directly related pairs of countries. Most potential trade links that have a high evaluation index value will have been fulfilled in recent years, although some will not have been fulfilled immediately, or make cooperation in other ways. However, the evolution of international crude oil trade has different practical meanings, and encourages these countries to have potential trade links to allow trading in certain future circumstances.

4.2. Prediction of potential trade links

Based on the potential linking motivation, we can predict potential trade links. Table 6 presents the country pairs from the top 10 in 2013 that had not yet fulfilled trade relations in 2014 and those pairs in the top 10 in 2014. These 11 pairs of countries are potential international crude oil trade partners because (i) they have a high possibility of cooperating in the real world and (ii) they are the pairs on which governments should focus. Our target is not to understand a clear establishment time, but to provide references for governments based on the topological attributes of each country.

Among these potential trade links, without considering external elements such as politics and economics, we predict that the five country pairs with no color shown in Table 6 will trade before 2018. Some of them have traded in the past few years with fluctuation, so they will cooperate by 2015 or 2016. In particular, the pairs of China and Germany and of Nigeria and Russia will not trade crude oil unless there is a breakthrough in trade relations according to our statistical results with comparison between potential and real trade links. Moreover, other four pairs of countries colored in blue will have possibility to exchange their imported crude oil under their high importation competition pressure. Although latter two kinds of country pairs may not happen in the near future, the evolution of all trade patterns will promote them trading.

4.3. Suggestions for trade strategies

Because of its influence on international crude oil trade, the number of common trade partners is essential for governments to consider when they develop their trade cooperation agreements with other countries. This provides an indirect method to construct trade links. For example, if non-OPEC country A wants to trade with country B, A can try to develop more trade relations with other countries that have traded with B. Meanwhile, if country C does not want A and B to cooperate, C can prevent them from having more similar trade partners. For instance, Japan and Germany had no crude oil trade relation from 2000 to 2014. If they want to establish trade links, Japan can develop crude oil trade cooperation with Germany's direct trade partners such as Canada, Brazil, and France.

Table 6
Estimation of future potential trade relationships.

	Pairs of countries		CN value		Pairs of countries		CN value
1	Japan	India	27	7	Brazil	Thailand	21
2	China	Germany	26	8	France	Thailand	20
3	China	India	26	9	Italy	India	20
4	India	United States	28	10	Japan	Spain	19
5	Japan	India	24	11	Nigeria	Russia	19
6	France	India	22				

Expanding common crude oil trade partners would thus promote the establishment of their trade links.

5. Conclusion

In this study, we use the link prediction approach to explore potential international crude oil trade links. In order to analyze the linking motivation of existing trade links, we define potential trade links based on countries' topological attributes, namely the number of common trade partners. We explore the common feature of test links and validate the chosen evaluation index to describe the real distribution of trade relationships. Furthermore, we examine the real evolution of potential trade links proposed from our structural perspective, and analyze the practical meanings of them with consideration of countries' crude oil roles.

Further studies should aim to incorporate the direction and volume of crude oil into the link prediction model to provide further perspectives and thus expand our understanding of international crude oil trade, including making more precise predictions about potential trade partners.

Acknowledgments

This research is supported by grants from the National Natural Science Foundation of China (Grant No. 71173199) and the Humanities and Social Sciences Planning Funds project under the Ministry of Education of the PRC (Grant No. 10YJA630001). The authors would like to express their gratitude to Weiqiong Zhong, Huajiao Li, Xiaoqi Sun, Xiaoqing Hao, Xiaoliang Jia, Lijun Wang, Xiaojia Liu and Xuan Huang who helped a lot during their work.

References

[1] Helpman E, Melitz M, Rubinstein Y. Estimating trade flows: trading partners and trading volumes. Q J Econ 2008;123:441–87.
[2] Duan W-Q. Estimating trade flow based on network topology. Phys A 2008;387:519–27.
[3] Yusaf TF, Yousif BF, Elawad MM. Crude palm oil fuel for diesel-engines: experimental and ANN simulation approaches. Energy 2011;36:4871–8.
[4] An H, Zhong W, Chen Y, Li H, Gao X. Features and evolution of international crude oil trade relationships: a trading-based network analysis. Energy 2014;74:254–9.
[5] Ji Q, Zhang H-Y, Fan Y. Identification of global oil trade patterns: an empirical research based on complex network theory. Energy Convers Manag 2014;85:856–65.
[6] Fagiolo G, Reyes J, Schiavo S. World-trade web: topological properties, dynamics, and evolution. Phys Rev E 2009;79.
[7] Zhang H-Y, Ji Q, Fan Y. Competition, transmission and pattern evolution: a network analysis of global oil trade. Energy Policy 2014;73:312–22.
[8] Zhong W, An H, Gao X, Sun X. The evolution of communities in the international oil trade network. Phys A 2014;413:42–52.
[9] Foschi R, Riccaboni M, Schiavo S. Missing links in multiple trade networks. In: 2013 ninth international conference on signal-image technology & internet-based systems (IEEE Computer Society, Japan); 2013.
[10] Lue L, Zhou T. Link prediction in complex networks: a survey. Phys A 2011;390:1150–70.
[11] Clauset A, Moore C, Newman MEJ. Hierarchical structure and the prediction of missing links in networks. Nature 2008;453:98–101.
[12] HongKun LIU, Lv L, Tao Z. Uncovering the network evolution mechanism by link prediction, Scientia Sinica Physica. Mech Astron 2011;41:816–23.
[13] Zhou T, Lu L, Zhang Y-C. Predicting missing links via local information. Eur Phys J B 2009;71:623–30.
[14] Sarukkai RR. Link prediction and path analysis using Markov chains. Comput Netw Int J Comput Telecommun Netw 2000;33:377–86.
[15] Lue L, Pan L, Zhou T, Zhang Y-C, Stanley HE. Toward link predictability of complex networks. Proc Natl Acad Sci U S A 2015;112:2325–30.
[16] Sherkat E, Rahgozar M, Asadpour M. Structural link prediction based on ant colony approach in social networks. Phys A 2015;419:80–94.
[17] Liu Z, Zhang Q-M, Lu L, Zhou T. Link prediction in complex networks: a local naive Bayes model. Euophysics Lett 2011;96.
[18] Guimera R, Sales-Pardo M. Missing and spurious interactions and the reconstruction of complex networks. Proc Natl Acad Sci U S A 2009;106:22073–8.
[19] Liu Z, Dong W, Fu Y. Local degree blocking model for link prediction in complex networks. Chaos 2015;25.
[20] Liben-Nowell D, Kleinberg J. The link-prediction problem for social networks. J Am Soc Inf Sci Technol 2007;58:1019–31.
[21] Lue L, Zhou T. Link prediction in weighted networks: the role of weak ties. Europhys Lett 2010;89.
[22] Lue L, Jin C-H, Zhou T. Similarity index based on local paths for link prediction of complex networks. Phys Rev E 2009;80.