



# The import competition relationship and intensity in the international iron ore trade: From network perspective

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## ABSTRACT

As a critical raw material, iron ore plays an important role in the development of the national economy, which results in intense competition between iron ore importers. Using the international iron ore trade data of the UN Comtrade from 2000 to 2015, this paper calculates the competition intensity between iron ore importers importing iron ore from the same exporters. The paper then constructs iron ore import competition networks with the importers as nodes, the import competitive relations as edges, and the competition intensity as weights of edges. Applying complex network theory, the paper analyzes the overall characteristics of the iron ore importing competition pattern, the import competition region and the main importing countries. The results reveal that the global iron ore import competition is tight, unbalanced and expanding and that the global iron ore import competitive pattern is moving from a core-periphery structure to a reticular structure. Although Australia and Brazil are both the main competition regions, the demand for Australian iron ore is more intense. The import competitive relations for iron ore exist primarily between Europe and Asia as well as intra-European and intra-Asian markets. The total import competition intensities between China and Japan and between China and South Korea are much larger than other competitive relationships with increasing trends from 2000 to 2015. We propose three policy recommendations for the importers: (1) diversifying the import channels; (2) enhancing the cooperation between importers; (3) investing in overseas equity mines to improve competitiveness.

## 1. Introduction

Iron ore is a strategic resource for national development. In addition to domestic production, countries, especially those lacking iron ore, compete against each other for the overseas resources to ensure the supply security of the resources. Thus, it is meaningful for scholars to investigate the international iron ore trade and related policy issues. Previous studies are categorized into two threads. The first one focuses on the demand side of iron ore. [Tcha and Wright \(1999\)](#) research the determinants of China's import demand for Australia's iron ore. [Wu et al. \(2016\)](#) systematically analyze the Chinese development strategy of iron ore. [Chen et al. \(2016a\)](#) identifies the influencing factors of China's iron import price. The second thread involves research on the supply aspect of iron ore. [Hurst \(2015\)](#) assesses the competitiveness of the supply side response to China's iron ore demand shock. [Lawrence and Nehring \(2015\)](#) study the impact of market structure differences on

the Australian iron ore industry. In addition to the research on the demand and supply of iron ore, scholars also focus on the international iron ore trade ([Labson, 1997](#); [Nakajima et al., 2011](#); [Toweh and Newcomb, 1991](#)).

However, there is little research on the competition among the importers of iron ore. The distribution of iron ore reserves across the world is uneven, and the productions are controlled by Australia, Brazil, and India. The World Steel Association reports in its Steel Statistical Yearbook 2016 that in 2015, with Australian iron ore production accounting for 40% of the global output, Australia is the largest producer of iron ore, followed by Brazil with 21%, and India with only 7%. Thus, there is intense competition among major consumers for the importation of iron ore. However, as each country generally imports iron ore from several suppliers, the competition is more complex, creating a complex competitive iron ore import system. Accordingly, other than analyzing the traditional international iron ore trade, the global

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competition pattern is also worthy of research to understand more deeply the international iron ore market. Through understanding their positions in the global iron ore trade system, importers can develop strategies for importing to improve their global competitiveness and status and secure the supply.

The analysis of the global competition pattern and study of the positions of numerous importers in the international iron ore trade call for a complex network analysis. The basic idea of a network analysis is to abstract the importers as nodes and the competition relations as linkages between the nodes. In this way, the topological characteristics of the system can be ascertained, and the major players and vital relationships can be identified. Because of its effectiveness, there is rich literature on applying network theory to international trade issues, some of which analyze the topological features of international trade (Fagiolo et al., 2010; Garlaschelli and Loffredo, 2005; Li et al., 2003; Zhong et al., 2016). There is also literature using complex network theory to study the relationships of competition. Teller et al. (2016) study the impact of competition and cooperation on the performance of a retail agglomeration. Li et al. (2014a) and Li et al. (2014b) construct the holding-based network to study business competition. Zhang et al. (2014) analyze the competition and transmission pattern of global oil trade based on complex network theory and provides a 5 C, i.e., changeability, contestability, cooperation, commitment, and circumstances, policy framework to improve the energy security of oil importers. Chen et al. (2016b) also uses complex network theory to analyze the competition pattern of global liquefied natural gas. An et al. (2014) analyze the international crude oil trade relationships using a trading-based network. To fill the research gap in the mineral resource network at the global level, this study attempts to use complex network theory to investigate the import competition in the international iron ore trade.

In this paper, we study the import competition intensity at three levels. We calculate the import competition intensity of each pair of competitors at the beginning, followed by the construction of the iron ore import competition network (IOICN) from 2000 to 2015. At the global level, we study the overall characteristics of the international iron ore trade competition pattern based on complex network indicators. Second, we analyze the competition with respect to the iron ore origins, namely, the competition objective level. Finally, we analyze the main competition intensity among importers, namely, the competition subject level. Then, based on the results obtained, we propose policy recommendations for the importing of iron ore.

The main contribution of this paper to the literature is the construction of an import competition network model to analyze the competition pattern and the positions of countries in the international iron ore trade. The remainder of this paper is organized as follows. Section 2 introduces the import competition model as well as the original data, and Section 3 analyzes the global import competition pattern at three levels. Section 4 then proposes policy recommendations, and Section 5 presents the conclusions.

## 2. Methods and data

### 2.1. Iron ore importing competition intensity

In this paper, we cite the indicator of competition intensity proposed by Zhang et al. (2014) to measure the level of competition between two countries importing iron ores from the same source. The specific indicator is defined as formula (1).

$$S_{ij} = \sum_c \left\{ \left( \frac{M_{ic} + M_{jc}}{M_w} \right) \times \left[ 1 - \frac{|(M_{ic}/M_i) - (M_{jc}/M_j)|}{(M_{ic}/M_i) + (M_{jc}/M_j)} \right] \right\} \times 100 \quad (1)$$

where  $S_{ij}$  denotes the competition intensity between iron ore importers  $v_i$  and  $v_j$ ,  $c$  represents the common iron ore import source  $v_c$ ,  $M_{ic}$  represents the iron ore import volume that importer  $v_i$  imports from  $v_c$ ,

**Table 1**

The maximum, minimum, and average values of competition intensity between country  $i$  and country  $j$ ,  $S_{ij}$ .

Year	Maximum	Minimum	Average
2000	0.338	1.59E-09	0.013
2001	0.364	2.89E-09	0.013
2002	0.356	3.16E-10	0.012
2003	0.346	1.54E-09	0.011
2004	0.382	3.86E-10	0.011
2005	0.434	2.33E-09	0.010
2006	0.456	7.01E-10	0.010
2007	0.453	6.31E-10	0.010
2008	0.477	1.73E-10	0.009
2009	0.571	3.64E-09	0.007
2010	0.526	1.98E-09	0.008
2011	0.515	3.38E-10	0.009
2012	0.575	1.39E-10	0.009
2013	0.592	3.11E-10	0.009
2014	0.650	1.40E-11	0.008
2015	0.688	3.56E-10	0.009

$M_{jc}$  represents the iron ore import volume that importer  $v_j$  imports from  $v_c$ ,  $M_w$  is the world's total iron ore import volume,  $M_i$  is the total import iron ore volume of importer  $v_i$ , and  $M_j$  is the total import iron ore volume of importer  $v_j$ .

In the theory, if there are only two countries country  $i$  and country  $j$  making iron ore trading in the world, then  $M_{ic} + M_{jc}$  should be equal to  $M_w$ , and  $M_{ic}/M_i$  should be equal to  $M_{jc}/M_j$ . As a result, the value of competition intensity indicator of country  $i$  and country  $j$  should be 1. If there are more than two countries in the international iron ore trading system, this indicator should be less than 1. And in a whole international iron ore trading system with more than two countries, as long as any two countries making iron ore trade, their competition intensity  $S_{ij}$  should be larger than 0. From the Eq. (1) we can see that, as for the same iron ore importing source country  $c$ , the larger the difference between  $M_{ic}/M_i$  and  $M_{jc}/M_j$  is, the competition intensity  $S_{ij}$  between country  $i$  and country  $j$  will be larger. The competition intensity measures the level of import competition between two importers with same importing source. The bigger of this value, the more intense of the competition. The maximum, minimum, and average values of competition intensity values are shown in Table 1.

From the Table 1 we can see that, in the iron ore importing competition network, the average level of competition intensity between two importers declines during the research period. In the same time, the range of the competition intensity between two importers become large, with the largest value becoming larger and smallest value becoming smaller.

We also have add top 3 competition intensity values in 2013, 2014 and 2015 in Table 2. From the Table 2 we can see that, the import competition intensity between China and Japan, South Korea and Indonesia are the largest in 2013, 2014 and 2015 with increasing trend. This indicates that the China is the most important iron ore importers and its competitors are mainly Japan, South Korea and Indonesia.

**Table 2**

Some examples with a few nodes and links.

Year	two competition countries	import competition intensity	rank
2015	China-Japan	0.69	1
2015	China-South Korea	0.63	2
2015	China-Indonesia	0.55	3
2014	China-Japan	0.65	1
2014	China-South Korea	0.58	2
2014	China-Indonesia	0.52	3
2013	China-Japan	0.59	1
2013	China-South Korea	0.5	2
2013	China-Indonesia	0.24	3

## 2.2. Iron ore importing competition network modeling

In this study, we construct import competition intensity networks of iron ore from 2000 to 2015. There are several elements in a network, such as nodes, edges, weight of edge and direction of the edge. In the iron ore importing competition network, nodes are countries, edges are the import competition relationship, the weights of edges are import competition intensity calculated through Eq. (1). As for the competition is mutual, thus the direction of the edges is undirected. What's more, we have revised the analyze part according to your specific comments. Thus, in these networks, the nodes represent the iron ore importing countries. If two countries import iron ore from the same exporters, these two countries establish an iron ore import competition relationship. Thus, the edges represent the iron ore import competition relationships, which are undirected. In the network, if country  $v_i$  and country  $v_j$  import iron ore from the same exporter, then a link in the network between node  $v_i$  and node  $v_j$  is drawn and  $a_{ij} = 1$ , whereas the weight  $w_{ij}$  of the edge between node  $v_i$  and node  $v_j$  is  $S_{ij}$ . Otherwise, no link is drawn and  $a_{ij} = 0$ . The indicators in the complex network are as follows:

### (1) The degree and cumulative distribution

The degree represents the number of import competitors that a given iron ore import country has in a given year. The cumulative distribution is the probability distribution of these degrees over the whole network. The degree index  $k_i$  is defined by formula 2 (Freeman, 1979), the average degree of network  $\langle k \rangle$  is defined by formula 3, and the degree cumulative distribution  $CP(k)$  is defined by formula 3.

$$k_i = \sum_{j=1}^{v_n} a_{ij} i = v_1, v_2, \dots, v_n \quad (2)$$

$$\langle k \rangle = \frac{\sum_{i=1}^N k_i}{N} \quad (3)$$

$$CP(k) = \sum_{K \geq k} p(K) \quad (4)$$

where  $k_i$  is the degree of iron ore importer  $v_i$ ,  $v_n$  is the set of all iron ore importers in a given year,  $\langle k \rangle$  is the average degree of the network,  $N$  is the total number of iron ore import countries as well as nodes in the network in a given year,  $CP(k)$  is the cumulative distribution of nodes whose degree is larger than  $k$ ,  $p(k) = N_k/N$  is defined to be the proportion of nodes with degree  $k$  in the network, and  $N_k$  is the number of nodes with degree  $k$ .

### (2) The weighted degree

The weighted degree represents the import competition intensity that an iron ore import country  $v_i$  has in the network. The weighted degree is defined by formula 5 ((Barrat et al., 2004)) and the average weighted degree of network  $\langle s \rangle$  is defined by formula 6.

$$s_i = \sum_{j=1}^{v_n} w_{ij} i = v_1, v_2, \dots, v_n \quad (5)$$

$$\langle s \rangle = \frac{\sum_{i=1}^N s_i}{N} \quad (6)$$

where  $v_n$  is the set of all iron ore importers in a given year,  $w_{ij}$  is the competition intensity  $S_{ij}$  between iron ore importers  $v_i$  and  $v_j$ .

### (3) Network diameter and average shortest path length

As for the iron ore importing competition networks are weighted networks, thus, we remove the weight and change them into non-

weighted networks. Assume that there are  $m$  shortcuts between node  $v_i$  and node  $v_j$ . The average shortest path length represents the average number of steps for each pair of import countries to construct an iron ore import competition relationship. The longest shortcut is the diameter of the network. Thus, the average shortest path length is defined as in formula 7 (Watts and Strogatz, 1998).

$$l = 1/m(m - 1)^* \sum_{i,j} d_{ij} \quad (7)$$

where  $d_{ij}$  denotes the shortest distance between nodes  $v_i$  and  $v_j$ . If node  $v_i$  and  $v_j$  cannot reach each other or if  $i = j$ , then the shortest distance  $d_{ij}$  is 0.

### (4) Clustering coefficient

The clustering coefficient of a country reflects the correlative degree of iron ore importing competition among its neighbors. The clustering coefficient is defined by formula 8 (Onnela et al., 2005).

$$c_i = \frac{1}{k_i * (k_i - 1)} \sum_{j,k} (a_{ij}^n a_{jk}^n a_{ki}^n)^{\frac{1}{3}} \quad (8)$$

where  $k_i$  is the degree of node  $v_i$ . Eq. (8) shows that the larger the clustering coefficient of one node, the closer the conversion among the neighbors of this node. As a result, this node is more important in the subgroup.

### (5) Core-periphery structure

Due to different iron ore import volumes, the importers play different roles in the competition pattern. The core/periphery structure is the idea of a group or network that cannot be subdivided into exclusive cohesive subgroups or factions, although some actors may be much better connected than others. (Borgatti and Everett, 1999) The core-periphery structure is used to explore densely connected core nodes and sparsely connected periphery nodes, both of which constitute the whole global iron ore import competition system, though the core nodes generally play a dominant role in the system (Zhang et al., 2014). The detection of the core-periphery structure denotes how well the current structure approximates an ideal core-periphery structure (Boyd et al., 2006). We choose the core-periphery detection model recommended by Borgatti and Everett (1999). The specific model is as follows:

$$\rho = \sum_{i,j} e_{ij} \delta_{ij}$$

$$\delta_{ij} = \begin{cases} 1 & \text{if } c_i = \text{CORE and } c_j = \text{CORE} \\ 0 & \text{if } c_i = \text{PERIPHERY and } c_j = \text{PERIPHERY} \\ & \text{otherwise} \end{cases} \quad (9)$$

In this model,  $\rho$  is the unnormalized Pearson correlation coefficient, and  $e_{ij}$  represents the actual relationships. If there are relationships between two nodes,  $e_{ij} = 1$ . Otherwise,  $e_{ij} = 0$ . And  $\delta_{ij}$  represents the ideal relationships among nodes, that is, a situation in which there are relationships among core nodes, no relationships among periphery nodes and relationships between core and periphery nodes are set as missing values.

## 2.3. Data

The data regarding the importing and exporting of iron ore among countries is obtained from the United Nations Statistics Division. The study period is from 2000 to 2015. The original data include 100 iron ore importing and 126 exporting countries and areas. Each type of commodity in the database has an HS code in the United Nations Comtrade Database. The HS code for iron ore is 2601. In addition, each country has an international ISO country code. The unit for iron ore trade volume is kilograms. Because some iron ore importing countries don't have the same importing source competitors, after establishing the iron ore importing competition network, there are 70 iron ore

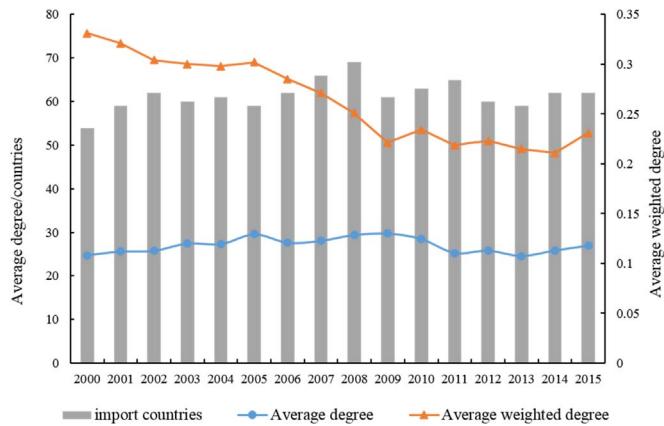


Fig. 1. The import countries, the average degree and average in the IOICN.

importing and 97 iron ore exporting countries and areas in the network.

### 3. Results

#### 3.1. Overall characteristics of the iron ore importing competition pattern

##### 3.1.1. The overall importing competition relationship

As evidenced in Fig. 1, the average degree slightly increased from approximately 25 in 2000 to approximately 27 in 2015, while the average weighted degree decreased from 0.331 in 2000 to 0.231 in 2015. Comparing the total number of iron ore importing countries, the average degree means that each importing country has an iron ore import competition relationship with approximately 40% of other countries. The increasing import countries and average degree indicate that the iron ore import market is expanding and that more competition relationships have formed between importers. Over the same period,

This may be caused by an increase in the import sources of each import country, thus allowing the importers to reduce their import risk and enhance their iron ore supply security. As a staple commodity and critical industrial raw material, countries attach great importance to the global trade of iron ore. Thus, the global iron ore market always evolves due to the development of the national economy and political and military events. During the development process, some importers may stop importing iron ore from foreign countries in a certain year, whereas new participants may enter the global market. From Fig. 1, it is noted that 2009 is an important turning point year. Before 2009, the number of iron ore import countries continues to increase, while at the same time, the existing importers expand their importing sources to develop their national economy. Through the import diversification strategy, importers reduce their competition intensity with single import competitors. However, because the global economic crisis of 2007–2009 spread to most countries and industries, the national consumption declined, which led to decrease in the demand for iron ore as well. As a result, giant international iron ore companies as well as some countries reduced their importing amount of iron ore. For instance, Rio Tinto sold the Brazilian iron ore business to Vale in 2009. After 2009, the global iron ore importing trade maintained relatively steady development.

To further understand the evolution of global iron ore import competition relationship, the evolutionary trend of the degree and cumulative degree distribution of the network is illustrated in Fig. 2. The Fig. 2 shows the power-law distribution and can be represented by a formula:  $CP(k) \sim k^{-\gamma}$ . Thus we denote the average degree  $\langle k \rangle$  and  $\gamma$  on it. From Fig. 2, it is noted that the exponential coefficient ( $\gamma$ ) decreased from 2000 to 2008 but slightly increased from 2008 to 2014, which indicates that the competition relationship faced by the iron ore importers increased before 2008, and then decreased after 2008, a phenomenon also proven by the evolution of the average degree of the

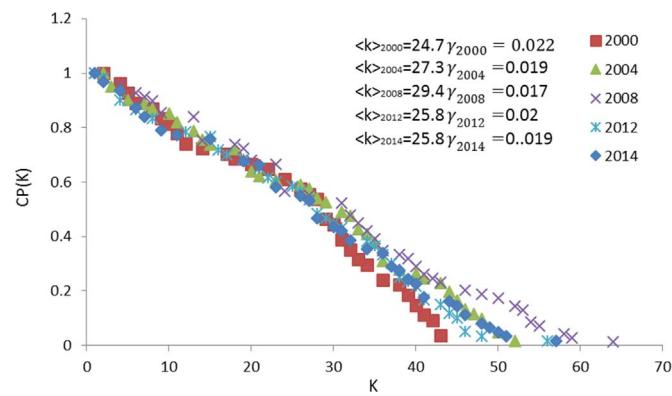


Fig. 2. The cumulative degree distribution.

network. Furthermore, with regard to the iron ore importers with many competitors, the competitive relationships become increasingly more complex.

##### 3.1.2. The overall import competition intensity

To understand the overall situation of global iron ore import competition intensity, we present the distribution of competition intensity in Fig. 3, in which it is evident that the competition intensity distribution is extremely unbalanced. The competition intensities of a few edges that are greater than 0.1 are far higher than others, while the majority of the edges are below 0.1, thus indicating that the most intense competition for iron ore occurs between a few countries. Comparing different years, the degree of imbalance worsens overtime. This means that iron ore importing competition occurs mainly between major importing countries, although the economy becomes more globalized. This also reflects that the competition between countries is also a competition for resources.

##### 3.1.3. The topology character of the non-weighted IOICN

Table 3 presents the yearly value of the network diameter, the average clustering coefficient and the average shortest path length of the non-weighted network from 2000 to 2015. Because we changed the weighted iron ore importing competition networks into non-weighted iron ore importing competition networks, thus the indirectly connected nodes and the shortest path length all reveal the relationships of importing competitors between each pair of importing competitors in the networks, which are irrelevant to the importing volume. Almost all values of the non-weighted network diameter are three, and the average shortest path length does not exceed two, indicating that in the IOICN, each importer can have a competitive relationship with other importers

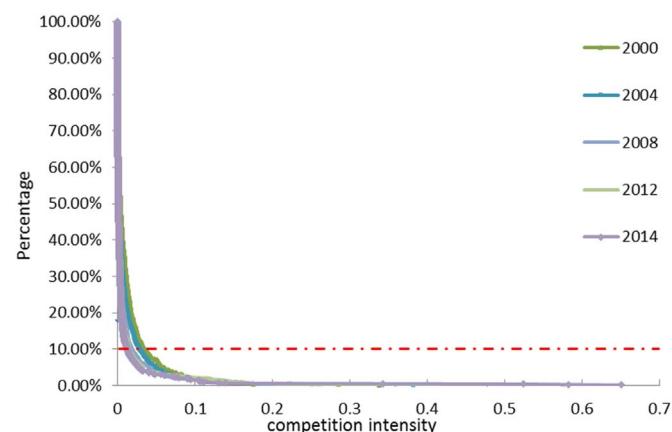


Fig. 3. Competition intensity distribution in 2000, 2004, 2008, 2012, and 2014. Note: the horizontal axis is the percentage of the edges in the network arranged in descending order of competition intensity.

**Table 3**

The network diameter, and average clustering coefficient and average shortest path length of non-weighted iron ore importing competition networks.

Year	Network Diameter	Average Clustering Coefficient	Average shortest path length
2000	3	0.84	1.572
2001	3	0.832	1.576
2002	3	0.845	1.612
2003	3	0.865	1.559
2004	3	0.854	1.58
2005	3	0.864	1.514
2006	3	0.85	1.576
2007	3	0.86	1.607
2008	3	0.846	1.575
2009	3	0.869	1.52
2010	3	0.86	1.568
2011	4	0.866	1.644
2012	3	0.857	1.581
2013	3	0.853	1.602
2014	3	0.864	1.591
2015	3	0.856	1.586

through two countries as intermediates. This verifies that the global iron ore import competition network is tight, a fact also verified by the average clustering coefficients with relatively high values greater than 0.83. The high average clustering coefficients mean that the competition between all competitors of a country is also extremely tight.

#### 3.1.4. The clustering at different competition level

To detect whether the competition network has clustering at different competitive levels, we present the average clustering coefficient distribution in Fig. 4, which reflects that there is a hierarchical structure in the IOICN. The clustering coefficient is relatively high when the degree of nodes is less than 30, thus illustrating that the IOICN presents the characteristics of the group. Thus, competition among iron ore importers with fewer competitors is prevalent, demonstrating the globalization of competition. As the node degree increases, the average clustering coefficient decreases, thereby indicating that with the increase in the competing countries of one importer, all of that one importer's competing countries have a lower probability of competing with each other.

#### 3.1.5. The core and periphery structure of the IOICN

To identify the core and periphery iron ore importers, we apply the core-periphery structure and draw the world maps, which are presented in Fig. 5. This indicator helps us to comprehend intuitively the spatial distribution of the main iron ore import competitive regions and the evolution of the structure of the competition pattern. From the maps, it is noted that in 2000, the iron ore importers in the four main areas, namely, the Asian-Pacific region, North America, South America and

Europe, were the core iron ore importers that dominated the development of the competition pattern. However, in 2004, the importers in North America and South America changed to periphery importers, and only countries in the Asian-Pacific and European regions continued to compete intensely. Then, in 2008, the importers in North America and South America regained their dominance. From this, it is inferred that although the economic crisis had a serious influence on the global economy, countries still focused on importing raw materials such as iron ore to promote economic recovery and development. However, by 2015, iron ore import competition became more globalized as more countries became core importers, and only small iron ore importers remained on the periphery. This increase in globalization indicates that the global iron ore import competitive pattern is moving from a core-periphery structure toward a reticular structure. Thus, as competitions among iron ore importers are interactive and mutually restrictive, changes by any importer affects other importers.

In Section 3.1, we analyze the overall characteristics of the international iron ore trade competition network. To understand a more detailed iron ore import competition pattern, we analyze the import competition region in Section 3.2 and the import competition among main importing countries in Section 3.

#### 3.2. The import competition region

To make the analysis of the import competition in iron ore origins more specific, we rank the main iron ore exporting countries according to their total export volumes in Fig. 6. Fig. 6 indicates that Australia and Brazil were ranked as the first and second largest iron ore exporters, respectively, from 2000 to 2015, and furthermore, before 2011, India was the third largest exporter of iron ore. However, it dropped sharply after 2011 and was ranked nineteenth in 2015. Conversely, South Africa became increasingly more important, and its iron ore export rank rose from sixth in 2000 to third in 2012, where it remained until 2015. In addition to South Africa, the Ukraine also became a crucial iron ore exporter. Accordingly, its iron ore exports soared from seventh in 2000 to fourth in 2015. Although the export status of Canada fluctuated slightly during 2000 and 2015, it has remained in the top six.

Countries mainly import iron ore from those exporters mentioned above. Thus, it is necessary to assess the export capacity of these exporting countries. A scatter plot of production and exports of all iron ore exporters is presented in Fig. 7. If a dot is on the dash line at the diagonal of the figure, it means that the production and export of this exporter is equal. The degree of deviation from the dash line to the lower right direction denotes the potential export capacity. If an exporter has a relatively high potential export capacity, importers can obtain more iron ore from that exporter in the future. The scatter plot reveals that Australia and Brazil dominate iron ore exports from 2000 to 2015 and that their iron ore production is primarily used for export. Before 2008, although Australia and Brazil had similar production and export rates, Brazil had greater potential export capacity than Australia. However, in 2012 and 2015, Australia both produced and exported far more iron ore than Brazil. Australia also reduced the potential export capacity gap with Brazil with values that were both relatively low. Thus, we infer that import competition of iron ore among importers is centered primarily on Australian and Brazilian iron ore and that the amount of iron ore that can be imported by importers from these two countries is relatively fixed.

Thus, we create a scatter plot of total competition intensity and average competition intensity for all iron ore exporters spanning several years in Fig. 8. Australia and Brazil, from 2000 to 2015, are denoted by special symbols. From this plot, it is evident that Australia and Brazil are the most intensely competitive iron ore export regions, whereas the iron ore competition in other markets is relatively sparse in comparison. The competition situations in Australia and Brazil belong to two different types of competition modes. For Australia, importers have relatively higher average competition intensity values but lower total

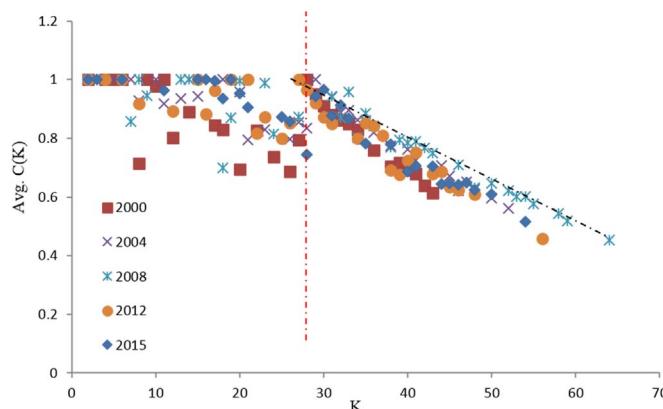


Fig. 4. The average clustering coefficient distribution.

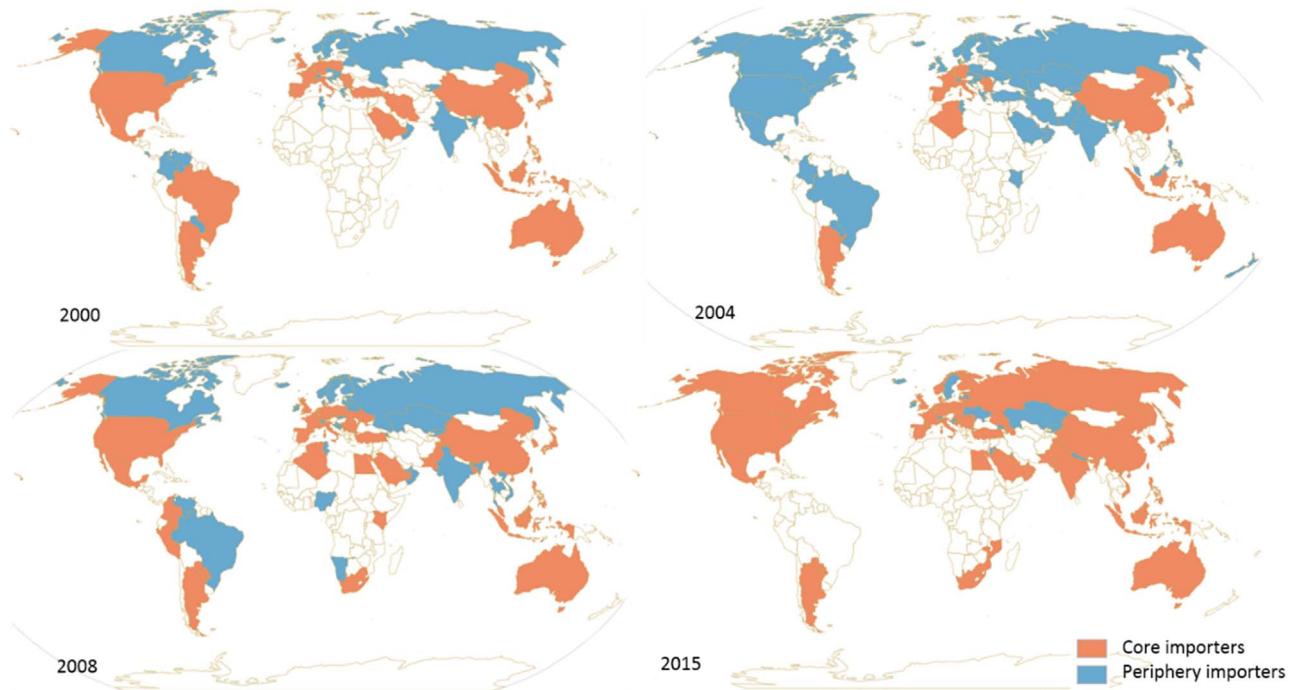


Fig. 5. The core-periphery structure in 2000, 2004, 2008 and 2015.

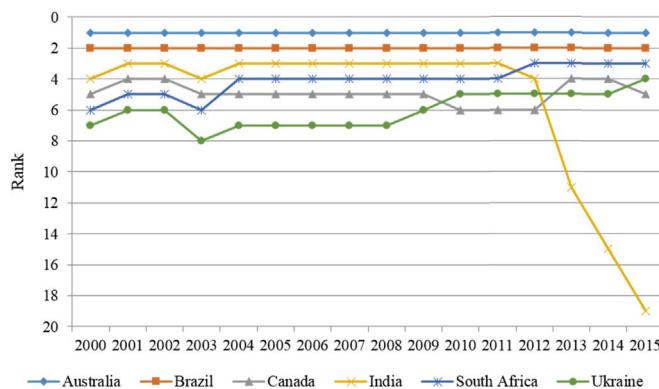


Fig. 6. The export rankings of main iron ore exporters.

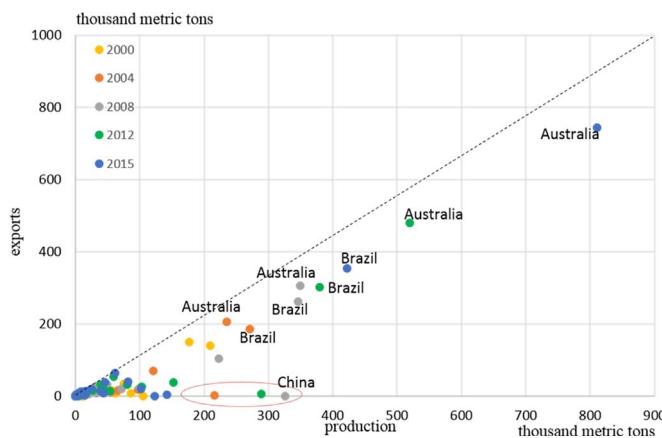


Fig. 7. The production and exports of all iron ore exporting countries in 2000, 2004, 2008, 2012 and 2015.

competition intensity values, which is just the opposite situation in Brazil. This indicates that while Brazil has far more import competition relations for its iron ore than Australia, the imports from Australia are

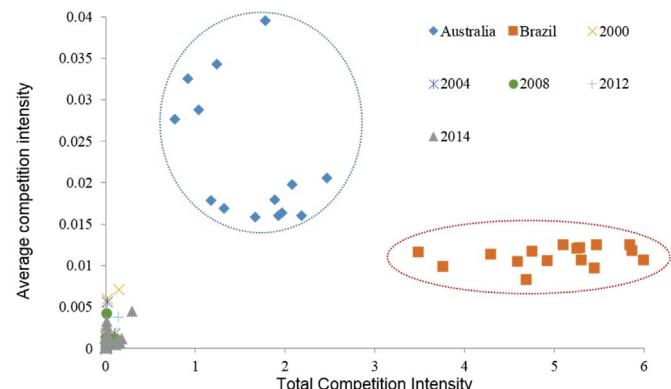
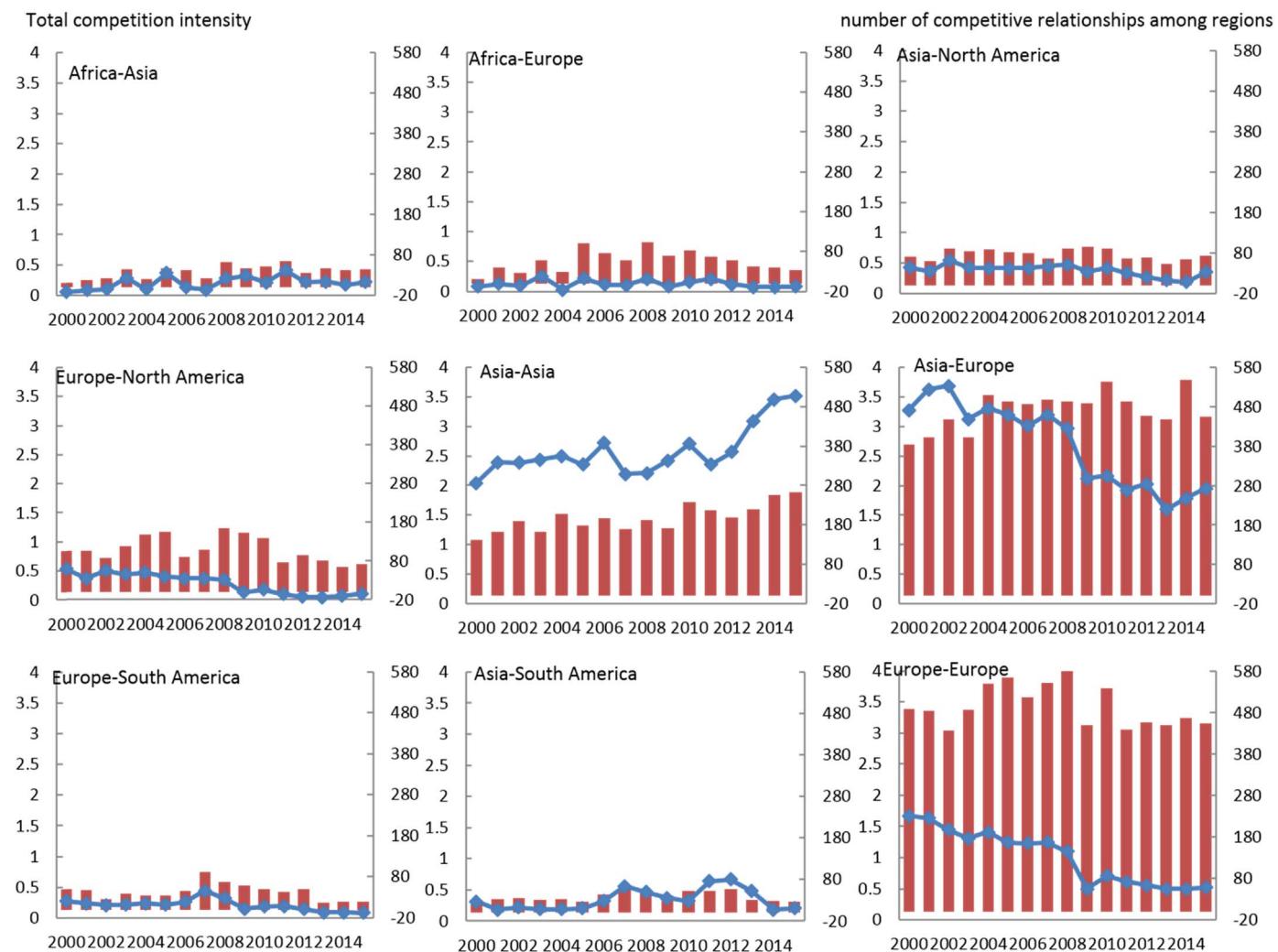


Fig. 8. The average competition intensity and total competition intensity of importing countries in different exporting markets in 2000, 2004, 2008, 2012 and 2014.

much larger than those from Brazil. Thus, the import competition for Australian iron ore is more intense than that for Brazilian iron ore, and accordingly, countries that import iron ore from Australia can expand their import sources to reduce the competition pressure and enhance their iron ore supply security.

### 3.3. The import competition among main importing countries

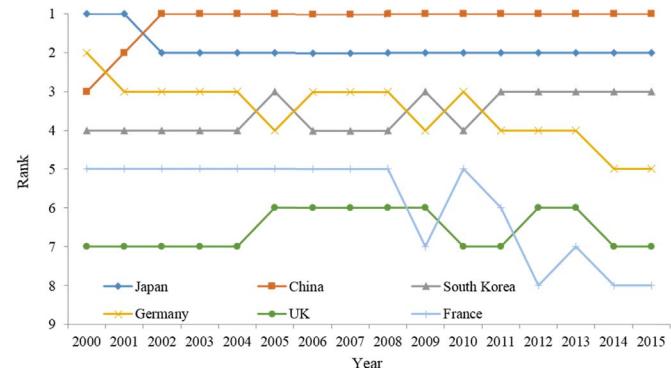
The competitive relationships among continents reflect the iron ore import competition pattern at the macro continental level (Fig. 9). The larger the number of competitive relationships, the more intense the competition between the corresponding continents. The results indicate that, as a whole, iron ore import competition is generally concentrated between Europe and Asia, though there is also intra-European and intra-Asian competition, which is related to the fact that most iron ore importers are located in Europe and Asia. There are also many competitive relationships between Europe and North America, as they both import iron ore from South America for geographical and transport cost reasons. The competition intensity increases significantly in intra-Asian countries but decreases in intra-European countries and between Europe and Asia. This suggests that although there are far



**Fig. 9.** The competition relationships and intensity among continents. Notes: The bars represent the number of competitive relationships among continents with the axis on the right side. The lines represent the total competition intensity with the axis on the left side.

more import competitive relationships in Europe and between Europe and Asia, the competition intensity is not excessive when compared with intra-Asian countries. This may be because Europe has a large number of iron ore importing countries, but the imports of these countries are not large. In contrast, whereas the number of importers in Asia is small, countries such as China and Japan import large amounts of iron ore, especially as a result of their recent economic development.

After analyzing the import competition pattern at the continental level, it is significant to detect the competition pattern at the country level. We rank the importers according to their weighted degree in the IOICN (Fig. 10). The weighted degree represents the total import competition intensity that importers faced in the competition network. It is obvious that China and Japan exhibit the greatest iron ore import competition intensity values from 2000 to 2015, which means that they bear the greatest competitive pressure. South Korea experiences the third greatest competition intensity since 2011. Thus, the top three countries with the highest import competition intensity are all Asian countries, a conclusion that is consistent with previous continental level results. With respect to European importers, Germany fell from second in 2000 to fifth in 2015, and France fell from fifth in 2000 to eighth in 2015. Only the United Kingdom remained stable, at seventh place, with a slight fluctuation during 2000 and 2015. Therefore, given that Asian countries such as China, Japan and South Korea and European countries such as Germany, France and UK are the main iron ore import competition countries, other iron ore importers should pay close attention



**Fig. 10.** The weighted degree rank of countries in the IOICN.

to these countries when they develop their iron ore trading policies.

The ten relationships exhibiting the greatest competition intensities from 2000 to 2015 are presented in Table 4. From this, it is noted that the greatest import competitions are concentrated among the large iron ore importers, such as China and Japan. Furthermore, the import competitions among China, Japan and South Korea occupy the most important place during the research period. Moreover, due to the absence of iron ore resources, the economic development in real estate and the infrastructure industry growth in China, it was necessary for

**Table 4**

The competitive relationships with the largest import competition intensity.

rank	2000	2001	2002	2003
1	China-Japan	China-Japan	China-Japan	China-Japan
2	Japan-South Korea	Japan-South Korea	Japan-South Korea	Japan-South Korea
3	Japan-UK	China-South Korea	China-South Korea	China-South Korea
4	Japan-Philippines	Japan-Philippines	Japan-UK	China-Netherlands
5	China-South Korea	Japan-UK	China-UK	China-UK
6	France-Japan	Japan-Turkey	China-Netherlands	Japan-UK
7	Germany-Japan	Japan-Netherlands	Japan-Netherlands	China-Romania
8	Japan-Netherlands	China-UK	Japan-Turkey	China-France
9	Japan-Romania	France-Japan	China-Turkey	China-Turkey
10	China-UK	China-Turkey	China-Germany	Japan-Netherlands
rank	2004	2005	2006	2007
1	China-Japan	China-Japan	China-Japan	China-Japan
2	China-South Korea	China-South Korea	China-South Korea	China-South Korea
3	Japan-South Korea	China-UAE	China-UAE	Japan-South Korea
4	China-UK	China-UK	Japan-South Korea	China-UK
5	China-Netherlands	Japan-South Korea	China-UK	China-Netherlands
6	China-Romania	China-Netherlands	China-France	China-Pakistan
7	China-Turkey	China-Romania	China-Pakistan	China-Romania
8	China-Pakistan	China-France	China-Turkey	China-France
9	Japan-UK	Japan-UK	China-Netherlands	China-Spain
10	China-France	China-Pakistan	China-Romania	China-Germany
rank	2008	2009	2010	2011
1	China-Japan	China-Japan	China-Japan	China-Japan
2	China-South Korea	China-South Korea	China-South Korea	China-South Korea
3	Japan-South Korea	China-Germany	China-India	China-Colombia
4	China-Romania	China-Italy	Japan-South Korea	China-Germany
5	China-UK	Japan-South Korea	China-Germany	Japan-South Korea
6	China-Netherlands	Australia-China	China-France	China-India
7	China-France	China-South Africa	China-Qatar	China-Netherlands
8	China-Germany	Belgium-China	China-Romania	China-USA
9	China-Turkey	China-Netherlands	Australia-China	Australia-China
10	China-Indonesia	China-Turkey	China-UK	China-Italy
rank	2012	2013	2014	2015
1	China-Japan	China-Japan	China-Japan	China-Japan
2	China-South Korea	China-South Korea	China-South Korea	China-South Korea
3	China-India	China-Indonesia	China-Indonesia	China-Indonesia
4	China-Colombia	China-Colombia	China-India	China-India
5	China-Germany	China-Pakistan	Japan-South Korea	China-Germany
6	China-Qatar	China-USA	China-Germany	Japan-South Korea
7	Japan-South Korea	China-Qatar	China-Qatar	China-Hungary
8	China-USA	Japan-South Korea	China-USA	China-USA
9	China-Netherlands	China-Germany	China-Netherlands	China-Saudi Arabia
10	China-Saudi Arabia	China-Saudi Arabia	China-UK	China-Qatar

Notes: The UAE represents the United Arab Emirates, and SK represents South Korea.

China to import large amounts of iron ore, which is the most important raw material for infrastructure industry, from Australia and Brazil to meet the domestic demand. In addition, the import competitions between Asian countries such as China, Japan and European countries such as UK, France remain intense from 2000 to 2015. In recent years, with Indonesia and the USA becoming China's main iron ore import competitors and creating substantial pressure with respect to China's import competition in the market, the challenges for China are particularly severe. In short, as China, Japan, South Korea and the European countries remain at the center of the world's iron ore consumption market, concomitantly, Asia and Europe become the most intense competitive area.

In addition, the competition among large iron ore importers plays an important role in the development of the iron ore import competition pattern. Thus, the main iron ore importers, such as China, Japan, South Korea, France, the United Kingdom, Italy and Germany, are selected for the exploration of the evolution of competition intensity, as presented in Fig. 11. From Fig. 11, it is noted that the total import competition intensities between China and Japan and between China and South Korea were much greater than other competitive relationships with increasing trends from 2000 to 2015. In contrast, the total import competition intensities between China and European countries, Japan and South Korea, and Japan and European countries were

extremely small and decreased during the research period. Thus, the competition between China and Japan is the most important competitive relationship in the iron ore import competition pattern.

Although China is the major iron ore demand country, Chinese enterprises have little iron ore pricing rights in the international iron ore trade market. In contrast to China, after nearly 50 years of iron ore strategic layout in the global market, Japan has established the most referential iron ore strategy in the world. First, Japan obtains overseas equity iron ore mines through their consortium and large steel enterprises. More specifically, for the mature iron ore supply countries such as Australia and Brazil, Japan directly purchases their iron ore mines or invests in their mining companies to gain stock rights. For emerging suppliers with lower entry thresholds, such as South Africa, Japan tends to possess the exploration iron ore mine rights. For suppliers with higher entry thresholds, such as India and the Ukraine, Japan prefers to buy their iron ore mines by capital mines. In this way, Japan establishes iron ore strategic reserves, while at the same time, the government and private enterprises share the responsibility. Thus, Japan has advantages in the iron ore international market, and the Japanese consortium along with the three major iron ore mining giants, i.e., Vale, BHP Billiton, and Rio Tinto, have close relationships. Since the 1960s, Japanese companies have actively participated in investing their iron ore resources to maintain a long-term stable supply of iron

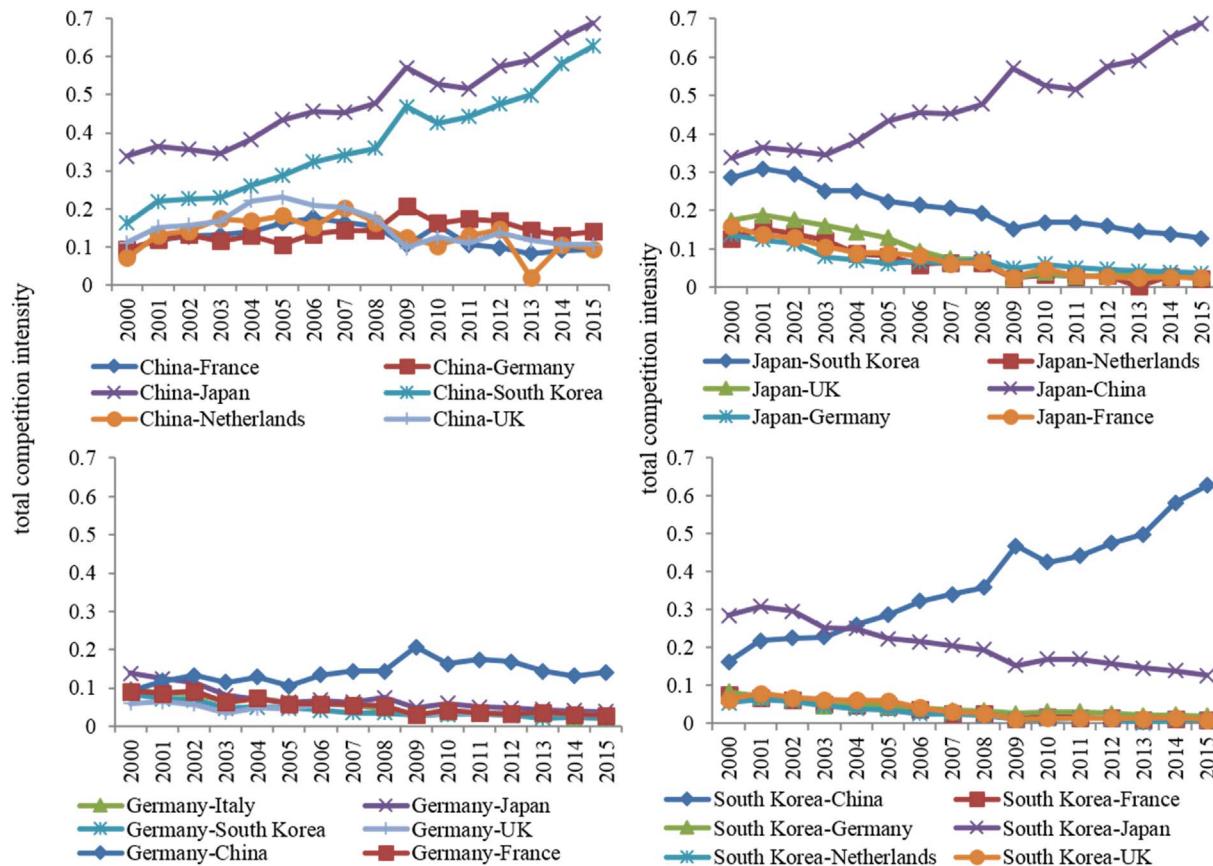


Fig. 11. The import competition between main iron ore importing countries.

ore. In 2003, The Mitsui, a Japanese enterprise, acquired a 15% stake in Valepar, the parent company of Vale, which is the world's largest iron ore producer, and it continues to expand its iron ore cooperation with Rio Tinto and BHP Billiton. As a result, Japan has far more iron ore pricing rights and a greater degree of competitiveness than China.

#### 4. Policy recommendations

With the development of the global economy, there are both opportunities and challenges in the international iron ore trade market. Therefore, each iron ore importer should develop appropriate strategies to adapt to the intense competitive environment. Accordingly, we propose policy recommendations for the international importing of iron ore.

##### (1) Diversification of import channels

Although Australia and Brazil are the most important iron ore exporters, there are other emerging and traditional exporters with abundant iron ore resources, such as South Africa and India. If importers only focus on the Australian and Brazilian iron ore, the import competition would be exceptionally fierce among the competitors. Furthermore, as the importers are vulnerable to supply disruptions that affect the domestic economic development, the importing countries must seek iron ore trading cooperation with new exporters to reduce their exiting competition pressure and enhance supply security.

##### (2) Enhancing the cooperation between importers

With the decrease in global iron ore resources, the competition for resources among importers is increasingly fierce. Nonetheless, they still find common interests that lead to cooperation. As buyers, every importer wishes to purchase iron ore at a relatively low price to reduce its production costs and restrain fluctuations in iron ore

prices, and thus reduce the adverse effects on downstream steel enterprises. In this way, the importers can establish alliances and deepen their interest foundation through mutual holdings, which results in more international discourse power with respect to iron ore negotiations.

##### (3) Obtaining overseas equity mines and improving competitiveness

In today's global world, the international iron ore market is mainly controlled by three iron ore international enterprises, namely, Vale, BHP Billiton, and Rio Tinto. Thus, most importers only accept the iron ore price as determined by these three organizations. For importing countries such as Japan, the steel enterprises should actively cooperate with the producers to obtain the overseas equity mines. For emerging suppliers in South Africa and Libya, because of their low entry threshold, importers can easily invest and participate in the primary stages of the iron ore production process, such as exploration and development, to gain more advantages in the international iron ore trade. Of course, if the steel enterprises have sufficient capital, they also should seek opportunities to purchase valuable iron ore mines or hold shares in the three big companies to improve their competitiveness.

#### 5. Conclusion

In this paper, we use competition intensity to measure the level of competition between two countries that import iron ore from the same source. We then construct import competition intensity networks of iron ore from 2000 to 2015, with importers as nodes, competitive relationships as edges and competition intensity as the weight of edges. According to complex network theory, we calculate the degree, weighted degree, clustering coefficient, network diameter, shortest path length, and core-periphery structure to analyze the global import competition pattern and obtain some valuable results that lead to

important policy recommendations.

First, the global iron ore import competition network is tight. The iron ore import market is expanding and more competitive relationships are being formed, while the average iron ore import competition intensity between importers are becoming weaker. In the history of iron ore development, 2009 is a critical year as the most intense competition for iron ore occurs between a few countries and the degree of the imbalance worsens. The global iron ore competitive import pattern is moving from a core-periphery structure toward a reticular structure.

By analyzing the competitive import regions, we find that Australia and Brazil are the first and second largest iron ore exporters from 2000 to 2015. As their potential export capacities are relatively low, the amount of iron ore that can be imported by importers from these two countries is relatively fixed. Although it is obvious that Australia and Brazil are the most intensely competitive iron ore export regions, there are far more competitive import relationships for Brazilian iron ore than for Australian iron ore, but the imports from Australia are much greater than those from Brazil. Thus, the import competition for Australian iron ore is more intense than that of Brazil.

Overall, iron ore import competition is generally concentrated between European and the Asian countries or intra-European and intra-Asian countries. As Asian countries such as China, Japan and South Korea and European countries such as Germany, France and UK are the main competitive iron ore import countries, other iron ore importers should pay more attention to these countries when developing iron ore trading policies. The total import competition intensities between China and Japan and China and South Korea were much greater than other competitive relationships with increasing trends from 2000 to 2015. Japan exhibits much greater iron ore pricing rights and competitiveness than other countries.

According to these results, we propose three policy recommendations for the importers: (1) diversification of import channels; (2) enhancing the cooperation between importers; and (3) investing in overseas equity mines and improving the level of competitiveness.

## Acknowledgement

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## References

- An, H., Zhong, W., Chen, Y., Li, H., Gao, X., 2014. Features and evolution of international crude oil trade relationships: a trading-based network analysis. *Energy* 74, 254–259.
- Barrat, A., Barthelemy, M., Pastor-Satorras, R., Vespignani, A., 2004. The architecture of complex weighted networks. *Proc. Natl. Acad. Sci. USA* 101, 3747–3752.
- Borgatti, S.P., Everett, M.G., 1999. Models of core/periphery structures. *Soc. Netw.* 21, 375–395.
- Boyd, J.P., Fitzgerald, W.J., Beck, R.J., 2006. Computing core/periphery structures and permutation tests for social relations data. *Soc. Netw.* 28, 165–178.
- Chen, W.H., Lei, Y.L., Jiang, Y., 2016a. Influencing factors analysis of China's iron import price: based on quantile regression model. *Resour. Policy* 48, 68–76.
- Chen, Z.H., An, H.Z., Gao, X.Y., Li, H.J., Hao, X.Q., 2016b. Competition pattern of the global liquefied natural gas (LNG) trade by network analysis. *J. Nat. Gas. Sci. Eng.* 33, 769–776.
- Fagiolo, G., Reyes, J., Schiavo, S., 2010. The evolution of the world trade web: a weighted-network analysis. *J. Evolut. Econ.* 20, 479–514.
- Garlaschelli, D., Loffredo, M.I., 2005. Structure and evolution of the world trade network. *Phys. A–Stat. Mech. Appl.* 355, 138–144.
- Hurst, L., 2015. Assessing the competitiveness of the supply side response to China's iron ore demand shock. *Resour. Policy* 45, 247–254.
- Labson, B.S., 1997. Changing patterns of trade in the world iron ore and steel market: an econometric analysis. *J. Policy Model.* 19, 237–251.
- Lawrence, K., Nehring, M., 2015. Market structure differences impacting australian iron ore and metallurgical coal industries. *Minerals* 5, 473–487.
- Li, H.J., An, H.Z., Gao, X.Y., Huang, J.C., Xu, Q., 2014a. On the topological properties of the cross-shareholding networks of listed companies in China: Taking shareholders' cross-shareholding relationships into account. *Phys. A – Stat. Mech. Appl.* 406, 80–88.
- Li, H.J., An, H.Z., Huang, J.C., Gao, X.Y., Shi, Y.L., 2014b. Correlation of the holding behaviour of the holding-based network of Chinese fund management companies based on the node topological characteristics. *Acta Phys. Sin.* 63.
- Li, X., Jin, Y.Y., Chen, G.R., 2003. Complexity and synchronization of the World trade Web. *Phys. A – Stat. Mech. Appl.* 328, 287–296.
- Nakajima, K., Nansai, K., Matsubae, K., Kondo, Y., Kagawa, S., Inaba, R., Nakamura, S., Nagasaka, T., 2011. Identifying the substance flow of metals embedded in Japanese international trade by use of waste input-output material flow analysis (WIO-MFA) model. *Isij Int.* 51, 1934–1939.
- Onnela, J.P., Saramaki, J., Kertesz, J., Kaski, K., 2005. Intensity and coherence of motifs in weighted complex networks. *Phys. Rev. E* 71, 4.
- Tcha, M., Wright, D., 1999. Determinants of China's import demand for Australia's iron ore. *Resour. Policy* 25, 143–149.
- Teller, C., Alexander, A., Floh, A., 2016. The impact of competition and cooperation on the performance of a retail agglomeration and its stores. *Ind. Mark. Manag.* 52, 6–17.
- Toweh, S.H., Newcomb, R.T., 1991. A spatial equilibrium-analysis of World iron-ore trade. *Resour. Policy* 17, 236–248.
- Watts, D.J., Strogatz, S.H., 1998. Collective dynamics of 'small-world' networks. *Nature* 393, 440–442.
- Wu, J.X., Yang, J., Ma, L.W., Li, Z., Shen, X.S., 2016. A system analysis of the development strategy of iron ore in China. *Resour. Policy* 48, 32–40.
- Zhang, H.Y., Ji, Q., Fan, Y., 2014. Competition, transmission and pattern evolution: a network analysis of global oil trade. *Energy Policy* 73, 312–322.
- Zhong, W.Q., An, H.Z., Fang, W., Gao, X.Y., Dong, D., 2016. Features and evolution of international fossil fuel trade network based on value of energy. *Appl. Energy* 165, 868–877.