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Key Factors Driving Competitiveness Between Bulk Cargo Ports: A Case Study in the Bohai Rim Port Cluster

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Abstract: This study examines the role of bulk cargo ports in improving supply chain efficiency within the Bohai Rim port cluster in China, addressing a gap in the research that has primarily focused on container ports. By analyzing 13 ports in the cluster through the shiftrate model and network analysis, this research aims to understand their adaptation to changing trade patterns and economic conditions. The Bohai Rim is a key hub for four major bulk cargo types—grain, coal, oil, and ore—each with distinct growth rates and trade networks. This research classifies the ports into four tiers based on their operational capabilities and market influence. Key findings reveal that the cargo transport network has shifted from a tri-power structure (Dalian, Tianjin–Tangshan, Qingdao–Rizhao port groups) to a dual-core pattern, now led by Tangshan and Qingdao Ports. Qingdao Port, with its advanced technologies and international orientation, has become a central player in global dry bulk transport. This shift reflects the changing dynamics of regional trade, with Qingdao's port technologies and global connectivity positioning it as a leader in the industry. This study provides valuable insights for port authorities, helping them understand the evolution of port systems and enhance the efficiency of neighboring ports.

Keywords: Bohai Rim port clusters; cargo port; shipping network; transport network; port centrality; dislocation competition

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Citation: Ye, F.; Xiao, Y.; Wei, C. Key Factors Driving Competitiveness Between Bulk Cargo Ports: A Case Study in the Bohai Rim Port Cluster. *Urban Sci.* **2024**, *8*, 237. https://doi.org/10.3390/urbansci8040237

Academic Editor: Peter V. Hall

Received: 31 August 2024
Revised: 15 November 2024
Accepted: 19 November 2024
Published: 2 December 2024

1. Introduction

With the development of globalization and the expansion of shipping networks, port services have evolved significantly. Initially, first-generation ports served primarily as basic cargo transport hubs [1]. With technological advancements and growing trade complexity, ports started offering a broader range of services, including specialized handling of different types of cargo (e.g., containerized goods, bulk commodities), value-added services, and better connectivity to inland transportation networks. Understanding port clusters' development, their significance, and related challenges is essential for maximizing their future potential. Since the 1960s, with the increasing degree of regional integration, port clusters have become a major focus of port geography research [2,3]. Rimmer advanced Taaffe's model by empirically analyzing the spatial structural evolution of port groups in Australia and New Zealand. He divided the port spatial evolution model into five stages [3], naming it the ideal time series model [4]. Later, Slack extended Taaffe's model using American ports as an example, adding a seventh stage to represent the further concentration of freight flow in network channels [5]. Concurrently, Barke examined European ports and established a five-stage model for the life cycle of container hub ports [6]. However, these port cluster studies have predominantly focused on the functions of container ports within a port cluster, often neglecting bulk ports or comprehensive ports that handle both bulk and container transport functions. This gap highlights the need for a more inclusive analysis encompassing all types of port services to better understand the dynamics and development of port clusters.

Previous research on port competition analysis has employed a variety of methodologies to understand and evaluate the competitive dynamics among ports. Quantitative methods such as econometric models, data envelopment analysis (DEA), and stochastic frontier analysis (SFA) have been used to measure port performance and efficiency [7,8]. These models help identify the determinants of port competitiveness by analyzing factors like throughput, pricing strategies, and market share [9–26]. Qualitative approaches, including case studies and SWOT analysis, provide in-depth insights into the competitive strategies, strengths, and weaknesses of specific ports [27]. Mixed methods such as port choice models and competitive benchmarking combine quantitative data with qualitative insights to understand the factors influencing port selection by shippers and carriers. Additionally, economic approaches such as analyzing market structure and concentration ratios and employing game theory models simulate competitive interactions and predict outcomes. These studies have highlighted the importance of strategic responses and efficiency improvements in maintaining competitiveness in a dynamic global market. However, most previous studies have focused primarily on the world's top container ports, often neglecting the significant contributions of bulk ports and comprehensive ports to regional and national economies [15–21,28–33].

Additionally, recent network analysis has also been pivotal in studying port competition. With the accessibility of shipping schedules for container liner transport and advancements in complex network theory, various indicators such as degree, centrality, small-world properties, and scaling laws have been proposed to measure port capabilities through their network positions [34]. Examples include analyzing transportation accessibility, optimizing shipping routes between Asia and North America [12,18,19,32,35–40], and assessing port accessibility in the Mediterranean region. Spatial analysis using geographic information systems (GISs) has also been employed for environmental impact assessments of port activities, market area analysis in the Gulf of Mexico, and planning port expansions in Southeast Asia [41]. These applications demonstrate GISs' powerful tools for visualizing and analyzing spatial data, aiding in informed decision making about container port development and management. However, the lack of network information for bulk ports makes it challenging to analyze their roles in trade dynamics and their economic significance, highlighting a critical gap in comprehensive port competition analysis [12,16,23–26,33,36,39,40,42,43].

Bulk ports handle a variety of raw materials, including coal, crude oil, petroleum products, iron ore, and grain, which are essential for socio-economic development and industrial processes. Unlike container ports, bulk ports face unique challenges due to the nature of the cargo they handle; bulk materials like coal, grain, and minerals necessitate specialized handling equipment and extensive storage facilities, leading to more complex and space-intensive operations [44]. Additionally, bulk cargo handling can generate dust and spillage, posing environmental and health concerns that require stringent controls. The transportation of these cargoes thus requires specialized facilities, such as dry bulk cargo storage areas, transshipment zones, and different types of dry bulk ships. The risk of cargo contamination and slower, more labor-intensive loading and unloading processes further complicate bulk port operations, contributing to operational inefficiencies and the need for diverse infrastructure compared with the standardized processes at container ports.

Despite the challenges, bulk ports offer significant opportunities. The consistent global demand for raw materials ensures a steady flow of goods through these ports, enabling them to capitalize on this demand by developing specialized services and niche markets [45,46]. By offering value-added services such as processing and refining raw materials, bulk ports can enhance their attractiveness and competitiveness. Strategic alliances with industries reliant on bulk goods, coupled with technological advancements in handling and storage, can further improve operational efficiency and environmental performance [47,48]. These initiatives allow bulk ports to establish competitive advantages and play a crucial role in the global trade network, complementing the functions of container ports. As dry bulk ports move towards specialization, they must consider the unique characteristics of different cargo types and tailor their trade networks and port strategies accordingly [48]. Therefore, exploring the dynamics of competition and cooperation between container ports and bulk ports within port clusters is essential. Understanding these interactions provides insights into their regional and international trade strategies, offering a comprehensive view of how port clusters adapt to the evolving global landscape.

According to a review of the literature, both bulk and container ports play critical roles in enhancing the supply chain efficiency of port clusters. However, most studies have primarily focused on container ports, with limited exploration of the development of and competition between bulk and container ports within a single cluster. This gap highlights the importance of analyzing the regional and international development differences in both types of ports, which is essential for port clusters to adapt to shifting trade patterns and economic conditions.

In this case study, we examine the Bohai Rim port cluster to explore the competition and cooperation dynamics among its 13 ports. The Bohai Rim region is a vital part of both China's and the global shipping network. According to the International Maritime Organization (2018), over 90% of global trade is conducted by sea. In 2019, China hosted 10 of the top 20 global freight traffic ports, with 7 located in the Bohai Rim. Facing Northeast Asia, the Bohai Rim cluster is supported by Hebei, Shanxi, Shaanxi, Henan, Shandong, and Inner Mongolia, with a hinterland encompassing China's main coal and grain production areas, as well as significant ore, petroleum, and derivative consumption zones. As a primary hub for north–south coal transport, it serves as the main marine entry point in northern China.

The transportation structure of the Bohai Rim port cluster evolved significantly between 1999 and 2019, mirroring the development process of bulk cargo port clusters and providing insights for the future growth of the Bohai Rim and other port clusters. By examining the differential growth rates of container and bulk ports and analyzing their global trade network patterns, this study aims to gain a deeper understanding of the dynamics of cooperation and competition within port clusters.

This study addresses the following research questions:

1. How do the regional and international development patterns of bulk ports within the Bohai Rim cluster influence competition and cooperation within the cluster?
2. How has the transportation structure of the Bohai Rim port cluster evolved over the past two decades, and what insights does this provide for the future dynamics of bulk port development within port clusters?

Previous research on port competition analysis has employed a variety of methodologies to understand and evaluate the topic. The shiftrate model overcomes limitations of traditional linear regression analysis by offering a straightforward and insightful approach to assessing ports' regional economic performance, identifying competitive strengths and informing targeted economic strategies by breaking down growth into port cluster components.

Secondly, this study applies network analysis to illustrate the topological features of the cargo transport network, revealing the complex interrelationships within the cluster. Finally, this study summarizes the regional bulk evolution patterns of the Bohai Rim port cluster, providing a more realistic depiction of port development within a port cluster shipping network.

The remainder of this paper is organized as follows: Section 2 defines the scope of the port cluster, Section 3 outlines the multi-dimensional port competition metrics, Section 4 presents detailed results, Section 5 discusses relevant implications, and Section 6 summarizes the main conclusions.

2. Study Area and Data Collection

2.1. Study Area

Bohai Rim port cluster occupies seven places in the top ten. It can be seen that China occupies a large share in global shipping, while Bohai Rim port cluster also occupies an important position in the transportation of bulk goods in China. The Bohai Rim port cluster is form of 13 ports, which are the main coal, ore, oil, and grain transportation ports in China (Figure 1). They are distributed in Liaoning, Hebei, Tianjin, and Shandong provinces, which are all important maritime external communication channels and gateways for maritime transport in northern China. The Bohai Rim port cluster is one of the five major port clusters in China. Port clusters usually consist of a group of ports located in the same region. Geographically, the Bohai Rim region is close to the major grain-producing areas in both northeast and central China and the traditional coal and iron mineral resource-producing areas such as Shaanxi, Shanxi, and Inner Mongolia. Its hinterland includes the northern half of China, radiating to Northeast Asia and connecting with Japan. It is the traditional node of iron ore, coal, and grain resources transfer, and the window for coal resource transport from producing regions to southern China by sea.

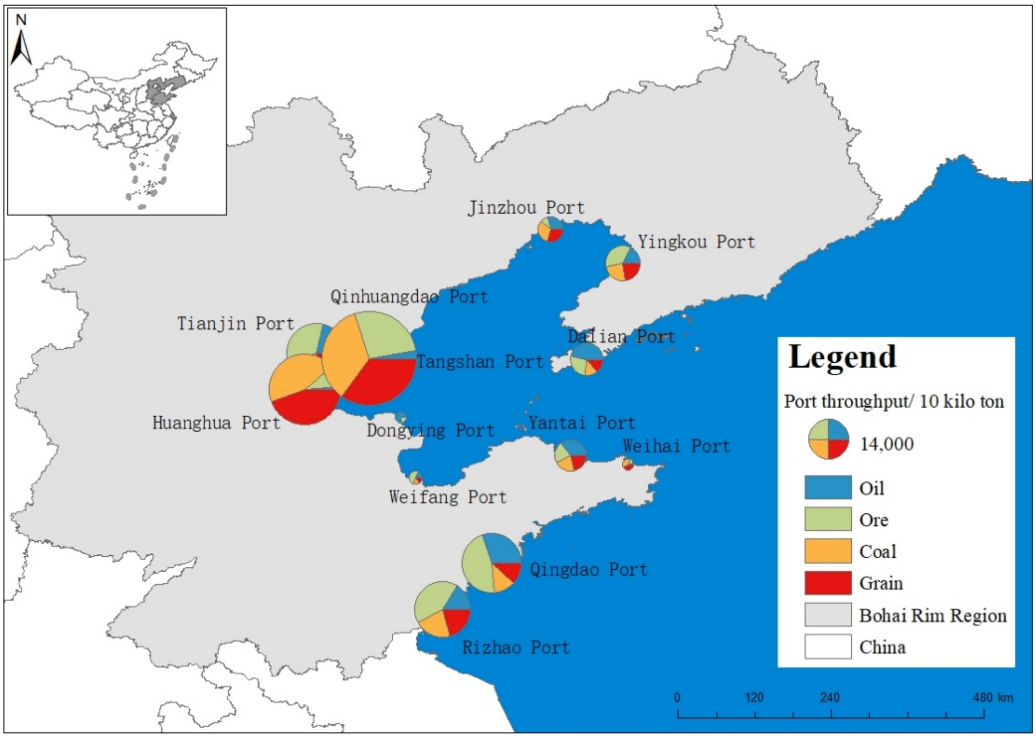

Figure 1. The geographical location of Bohai Rim port cluster.

2.2. Data Collection

Data mentioned in this article, such as the bulk cargo port and throughput data, were obtained from the *China Ports Yearbook* and Mysteel Corporation. From 1999 to 2019, China's ports around the Bohai Sea developed rapidly (Figure 2). However, since 2020, affected by the COVID-19 pandemic, uncertainties of port throughput data have increased. Therefore, this study collected both the throughput and shipping network data for the oil, coal, ore, and grain throughput of 13 ports around the Bohai Sea and the total cargo throughput data of four provinces around the Bohai Sea (Liaoning, Hebei, Tianjin, and Shandong Province), from *China Ports Yearbook* and Mysteel from 1999 to 2019, which was used to calculate and analyze the transportation networks of different types of cargo. The spatial distribution and evolution characteristics of different types of bulk cargo transfer centers in the Bohai Rim region can be understood through the throughput data of each port over the years.

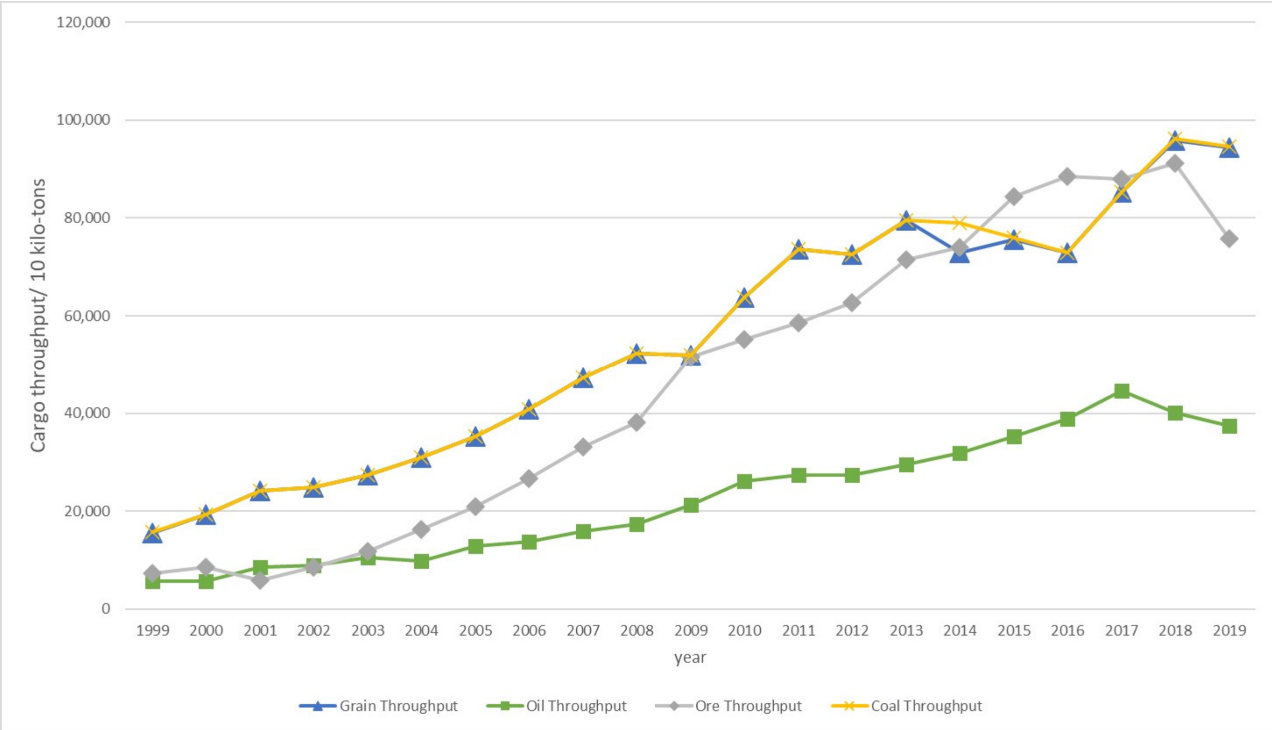

Figure 2. The trend of cargo throughput in Bohai Rim port cluster.

3. Methodology

3.1. Shiftrate

The shiftrate model can be used to determine competition intensity between ports [43]. Researchers have found that if a port has a positive shift value, it receives a competitive advantage. Conversely, if a port has a negative shift value, it is at a competitive disadvantage. However, the difference in the initial absolute volume is visible in the cargo throughput at each port. Thus, the growth rate and change of ports in this study were determined using the shiftrate. The shiftrate of port I is the difference between its share growth and absolute growth at time $t1$, where n is the number of ports:

$$SHIFT_{it1} = KT_{it1} - \frac{\sum_{i=1}^{n} KT_{it1}}{\sum_{i=1}^{n} KT_{it0}} \times KT_{it0}$$

$$SHIFTRATE_{it1} = \frac{SHIFT_{it1}}{KT_{it0}}$$

where $SHIFT_{it1}$ represents port I's offset growth between year $t0$ and year $t1$, $SHIFTRATE_{it1}$ represents the intensity port competitiveness of port I between year $t0$ and year $t1$, KT_{it0} and KT_{it1} reflect the cargo throughput of a certain port between year $t0$ and $t1$, $\sum_{i=1}^{n} KT_{it0}$ and $\sum_{i=1}^{n} KT_{it1}$, respectively, indicate the summary of cargo throughput in Bohai Rim port cluster at $t0$ and $t1$. The shiftrate of port I is represented by $SHIFTRATE_{it1}$. The greater $SHIFTRATE_{it1}$, the faster rate of development port I has. On the other hand, a lower $SHIFTRATE_{it1}$ indicates a slower pace of port growth.

3.2. Spatial Analysis

Spatial analysis is a quantitative study of geospatial phenomena, which can well explain geographical phenomena in urban space [49]. This paper analyzes the correlations of the spatial patterns of various bulk cargo ports and summarizes the reasonable spatial distribution of different types of cargo ports under the efficient port logistics mode. At the same time, the spatial correlation analysis of the port cargo transportation network, port hinterland, and port storage area is presented to explore how different types of cargo should be distributed in the context of port cluster development, so as to achieve an efficient, stable, and healthy mode of operation.

3.3. Visual Interpretation Method

In addition to manually calibrating ground objects after obtaining satellite images, visual interpretation also plays a significant role in the corresponding analysis of spatial structures calibrated on maps and the calculation of data [50]. It can be used to analyze and extract the spatial structure of freight transport in the study area in a qualitative way. Therefore, after calculating and obtaining the port throughput and competitiveness, this paper includes a transportation network map of different types of goods in the study area, obtained through visual interpretation observation. Combined with port competitiveness in different periods, the spatial–temporal evolution path and influencing factors related to the transportation networks of different types of goods are analyzed.

4. Results

4.1. Trend of Cargo Throughput in Bohai Rim Port Cluster

Ports play a role in the distribution of goods, and the cargo throughput reflects the level of the port in the port group. Figure 3 shows that the throughput of oil, coal, ore, and grain, representing the four major bulk commodities in the four provinces and the cities around the Bohai Sea, steadily increased from 1999 to 2014. Although there have been varying degrees of fluctuations after 2017, the throughputs of these four kinds of goods are still far ahead of other bulk cargo ports in China.

Around 2009, the volume of bulk cargo at the port generally increased rapidly, among which ore, coal, and grain were the most obvious commodities. As shown in Figure 3, a single province was usually mainly responsible for the transportation of a certain class of goods. With the passage of time, port freight structures may change due to competition between ports and hinterlands. Before 2011, ore was mainly carried by Qingdao Port and Rizhao Port. However, after 2005, the ore throughput of Qinhuangdao Port increased rapidly. In 2009, it surpassed Tianjin Port for the first time to become the third largest ore throughput port in the Bohai Rim region. In 2011 and 2012, it replaced Qingdao Port and Rizhao Port to become the largest ore transshipment port and has remained so ever since.

Grain and coal transportation mainly take place at the ports in Hebei Province. Tangshan Port has developed rapidly since 2007, and the throughput of all kinds of cargo has risen rapidly, among which the growth curve of coal and grain has been the sharpest. From 1999 to 2009, Tianjin Port accounted for a large proportion of coal and grain transportation, but its volume was relatively stable, neither declining sharply nor growing significantly, and it was surpassed by Tangshan Port in 2010.

The long coastline has promoted the growth of port cargo throughput, and the main bulk cargo ports are located on the coast of northern China. According to Table 1, by 2019, the Bohai Rim port group had steadily come to occupyd seven seats in the world's top 20 ports in terms of cargo throughput (a total of 14 ports in China were selected). Before 2014, only three seats in the world's top 20 ports in terms of cargo throughput were occupied by Bohai Rim ports, namely, Tianjin Port with 540 million tons, Qingdao Port with 468 million tons, and Dalian Port with 423.4 million tons. In 2015, Qinhuangdao Port was added to the list, with 253.1 million tons, ranking fourth in Bohai Rim and fourteenth in the world. In 2016, Qingdao replaced Tianjin as the leading port in terms of cargo throughput in the Bohai Rim, with 484.5 million tons. In 2017, Tangshan's cargo throughput surpassed Qingdao's to reach 573.2 million tons, and its position has been maintained since then. Therefore, Tangshan Port is recognized as the port with the highest total cargo throughput in China, followed by Qingdao, Tianjin, Dalian, Rizhao, Yantai, Yingkou, and Huanghua

Port, all of which are among the top 20 cargo ports in China. The change in the ranking of cargo throughput shows that the growth rate of the Tianjin–Tangshan and Qingdao–Rizhao groups has increased, while that of the Dalian group has decreased.

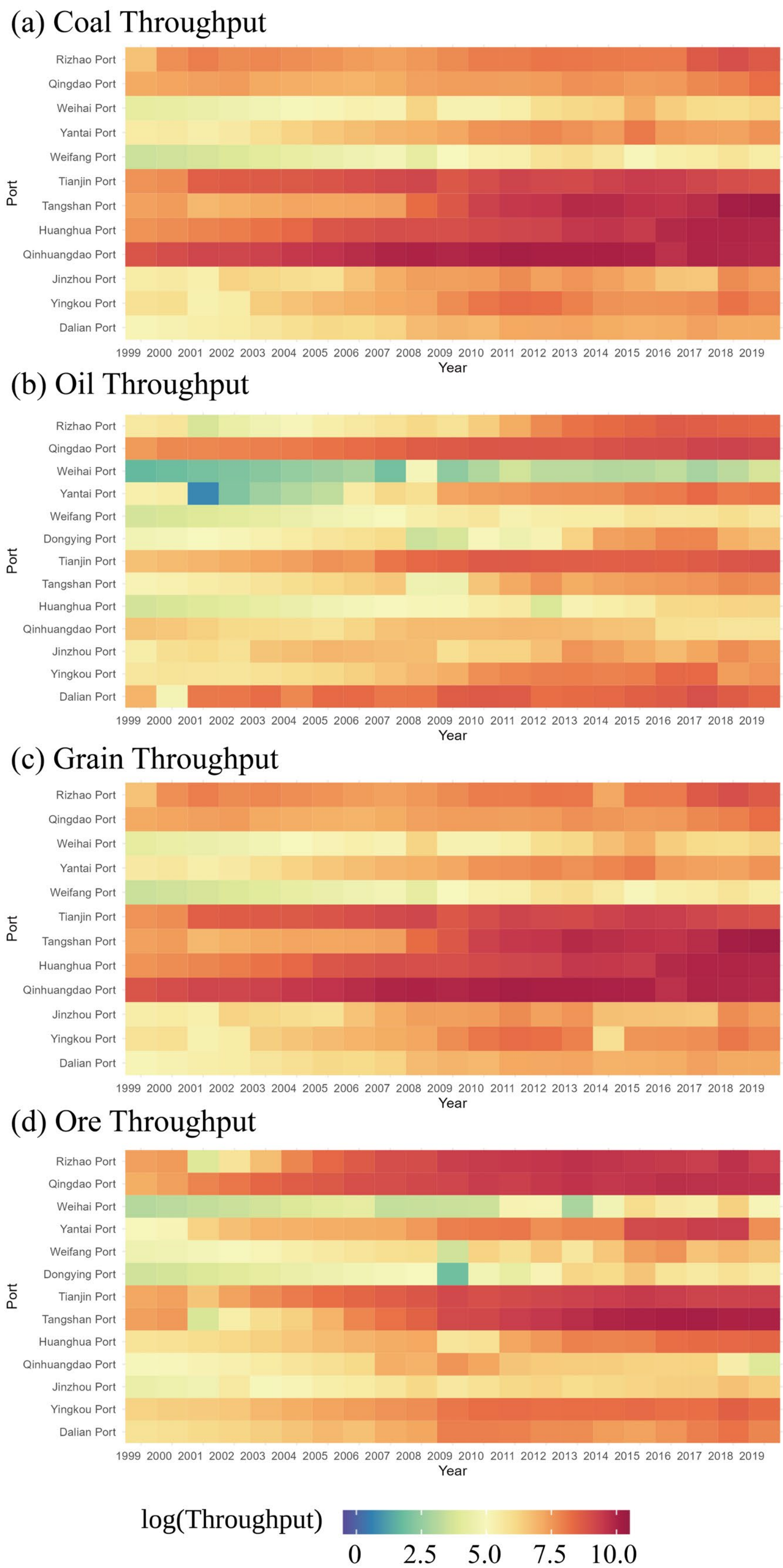

Figure 3. Oil, ore, coal, and grain throughput in Bohai Rim port cluster.

Table 1. List of the world's top 20 ports from 2014–2019. Ports within the Bohai Rim cluster are highlighted in bold (Data source: *China Ports Yearbook*).

Port Ranking	2014	2015	2017	2018	2019
1	Shanghai Port	Shanghai Port	Ningbo Port	Ningbo Port	Ningbo Port
2	Port of Singapore	Port of Singapore	Shanghai Port	Shanghai Port	Shanghai Port
3	**Tianjin Port**	**Tianjin Port**	Port of Singapore	**Tangshan Port**	**Tangshan Port**
4	Ningbo Port	Ningbo Port	Suzhou Port	Port of Singapore	Port of Singapore
5	Guangzhou Port	Guangzhou Port	**Tangshan Port**	Guangzhou Port	Guangzhou Port
6	**Qingdao Port**	**Qingdao Port**	Guangzhou Port	**Qingdao Port**	**Qingdao Port**
7	Port Hedland	Port of Rotterdam	**Qingdao Port**	Suzhou Port	Suzhou Port
8	Port of Rotterdam	Port Hedland	Port Hedland	Port Hedland	Port Hedland
9	**Dalian Port**	**Dalian Port**	**Tianjin Port**	**Tianjin Port**	**Tianjin Port**
10	Port of Busan	Port of Busan	Port of Rotterdam	Port of Rotterdam	Port of Rotterdam
11	Port of Hongkong	Port of Kuangyang	**Dalian Port**	**Dalian Port**	Port of Busan
12	**Qinhuangdao Port**	Port of South Louisianna	Port of Busan	Port of Busan	**Rizhao Port**
13	Port of South Louisianna	Port of Hongkong	**Yingkou Port**	**Yantai Port**	**Yantai Port**
14	Port of Houston	**Qinhuangdao Port**	**Rizhao Port**	**Rizhao Port**	**Dalian Port**
15	Shenzhen Port	Port of Houston	Port of Kuangyang	**Yingkou Port**	Nantong Port
16	Port Klang	Port Klang	**Yantai Port**	Port of Kuangyang	Zhenjiang Port
17	Port of Nagoya	Shenzhen Port	Zhanjiang Port	Zhanjiang Port	**Huanghua Port**
18	Xiamen Port	Xiamen Port	Port of Hongkong	**Huanghua Port**	Taizhou Port
19	Port of Antwerp	Port of Antwerp	Port of South Louisianna	Port of South Louisianna	Port of Kuangyang
20	Port of Los Angeles	Port of Nagoya	Nanjing Port	Nantong Port	Port of South Louisianna

As evidenced by the changes in the top 20 ports in the world (Table 1), the rankings of Tangshan Port and Rizhao Port have risen rapidly. Tangshan Port ranked first in the Bohai Rim port cluster and fifth in the world cargo port ranking, and two years later it became the third in the world ranking. Rizhao Port rose from 6th in Bohai Rim and 14th in the world in 2017 to 4th in Bohai Rim and 12th in the world by the year 2019. This shows that the ports in Bohai Rim port cluster had been greatly developed during this period, especially the Tianjin–Tangshan and Qingdao–Rizhao groups. It is worth noting that in the 20-year study period, the regional center ports of Qinhuangdao, Tangshan, Huanghua, Tianjin, Rizhao, and Qingdao all had one or more types of cargo throughput in the top three in the port group, and there was a large gap between the throughput of other small and medium-sized ports and these central ports.

4.2. The Cargo Transport Network Connection of Bohai Rim Port Cluster

The transportation networks of coal, ore, oil, and grain present different network structures and they underwent different evolutions from 1999 to 2019. In the 20-year study period, taking every 5 years as a time node, four time points were selected in order to examine cross sections, and the annual throughput of four types of cargo in 13 ports around the Bohai Sea was calculated. After the data acquisition was completed, the ports were first sorted according to their throughput, and those whose throughput was less than half that of the previous port were classified into another grade. Finally, the 13 ports have been divided into four tiers: the first tier, indicated with red circles, are the three ports with the largest throughput, which are the regional center ports; the second tier with a blue circle represents the sub-center of the region; the third tier with the white circle represents the relatively marginal ports, which are usually not the main transshipment ports for the type of cargo; the fourth tier, marked with a black circle, represents the marginal ports within the port group, which have small volumes and do not or rarely undertake the transportation of bulk cargoes (Figure 4).

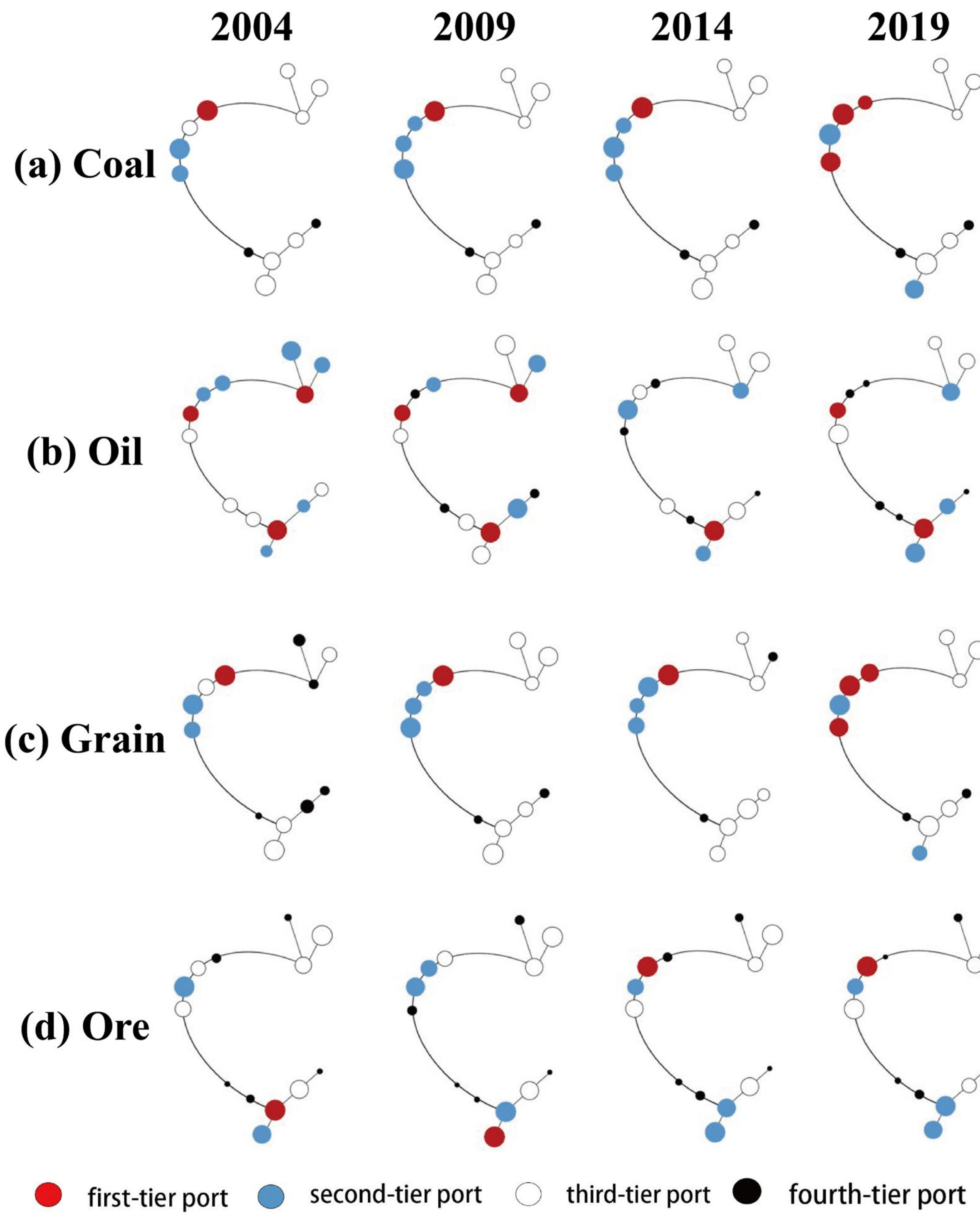

Figure 4. The structure of the Bohai Rim port cluster transportation network.

4.2.1. Coal Transportation Structure

The center of coal transportation is concentrated in the Tianjin–Tangshan group. This is because the ports in this region primarily handle transshipments, because the Daqin Line and other special railway lines for coal transportation may be used to travel directly from hinterland coal mines to ports like Qinhuangdao. The agglomeration of coal transportation is relatively obvious. Developing from the first-level central port to the periphery, ports from the same group but at a certain distance from the central port are likely to be developed first. For example, the distances between Tianjin Port, Huanghua Port, and Qinhuangdao Port are farther than from Tangshan Port. Therefore Tangshan port remain to be second-tier port while other ports in Tianjin-Tangshan port group have developed into first-tier ports. After 2014, the spatial agglomeration of major coal ports gradually became significant. The central port first tier changed from Qinhuangdao Port to include Qinhuangdao, Tangshan, and Huanghua Ports, among which Tangshan Port surpassed the others and became the largest coal transshipment center in the Bohai Sea port group, while Qinhuangdao Port fell to the bottom of the first-tier port category. The Tianjin–Tangshan port group, which is located on the Bohai Bay, has an obvious monopoly effect and undertakes the vast majority of coal transportation functions. The Qingdao–Rizhao port group and Dalian–Yingkou–Jinzhou port group exporting from the Bohai Bay have little advantage in relation to this type of cargo transportation.

4.2.2. Oil Transportation Structure

The oil transportation center was initially concentrated in Dalian, Huanghua, and Qingdao Ports and spread out along the coastline in accordance with distance. In 2009, the agglomeration effect of large ports in the oil transportation network was enhanced, and several major ports took up the vast majority of capacity. In 2014, the agglomeration effect was more significant, and oil transportation was concentrated in Qingdao Port. In 2019, the economic effect of agglomeration began to be reflected, and oil transportation spread from Qingdao to Tianjin Port in the north, and other places.

4.2.3. Grain Transportation Structure

Grain transportation was concentrated in the Tianjin–Tangshan region and gradually spread southward along the coastline. Before 2014, Qinhuangdao Port, as the first-tier core port in the region, undertook the main grain transshipment business. However, after 2004, the adjacent Tianjin, Huanghua, and Tangshan Ports developed rapidly and each successively become the second largest grain transshipment port in the region. By 2019, grain transportation had developed into a three-core structure, with Tangshan Port in the middle as the centre and Qinhuangdao Port and Huanghua Port, respectively, on the south and north sides. Meanwhile, the Dalian–Yingkou cluster and Qingdao–Rizhao cluster have been in relatively marginal positions in the grain transport business. Although they are developing steadily, there is still a significant gap between them and the Tianjin–Tangshan cluster.

4.2.4. Ore Transportation Structure

There has been a relatively obvious spatial transfer of the ore transportation network. In the early 21st century, Qingdao Port undertook the main ore transportation business, forming a dual-core structure with Qingdao as the main center and Tianjin as the sub-center in the Bohai Rim port cluster. Then, with the two port cities as the center, this expanded to the surrounding ports according to geographical proximity. In 2014, the main center shifted to Tangshan Port, Rizhao Port, Qingdao Port, and Tianjin Port, as the second-level center ports played an auxiliary role. The port transportation structure in northeast China is relatively stable, maintaining the structure of Dalian Port and Yingkou Port as the main transshipment ports and Jinzhou Port as the auxiliary.

4.3. Port Competition Within Bohai Rim Port Cluster

Different types of goods show different competitiveness in different time periods. According to the calculation formula of port competitiveness (Figure 5), a positive value for the off-set growth rate means that the port has strong competitiveness, and the competitiveness gradually increases with the increase of shiftrate. When the off-set growth rate has a negative value, it means that the port has weak competitiveness within the port group, and the smaller the number is, the weaker the competitiveness the port has.

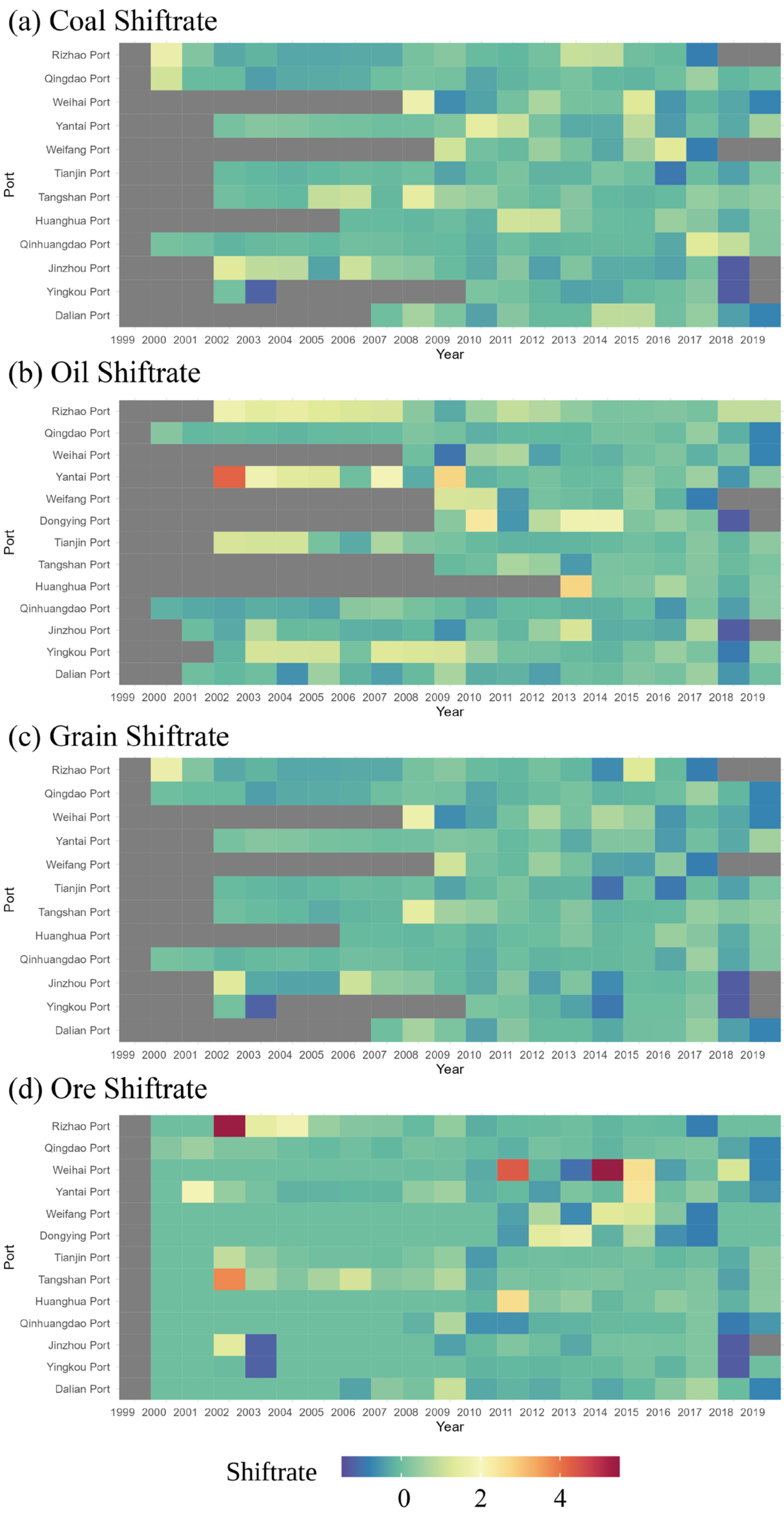

Figure 5. The shiftrate of the Bohai Rim port cluster.

Port competitiveness can be understood as the ability of a port to enhance its centrality by attracting shipping demand to shift to it. Generally speaking, due to the long development history of regional central ports, their port volumes have reached high levels, and there is no need to participate in competition within the port group; so, the port's competitiveness value is low. Similarly, small ports on the periphery of the region have too little leverage to compete, and thus remain at a low level of competitiveness. Only medium-sized ports are affected by the international trade situation, domestic policy, and other factors, and their port competitiveness value and status in the port group are often in a state of fluctuation.

4.4. External Contact with the Bohai Rim Port Cluster

The port-to-port network model diagram reflects the intensity of port cooperation and shows the degree of overlap between the port cluster and the major dry bulk cargo trade ports for foreign trade (Figure 6). Huo et al. pointed out that Chinese ports are developing towards a provincial port cluster direction [47]. Tagawa's study found that the reason for port cooperation is that geographically proximate ports have overlapping businesses, and by cooperating, they can achieve mutual benefit and avoid excessive competition [51]. For example, the cooperation between Dalian and Yingkou Ports exists to avoid such competition. Geographically proximate ports have similar locational conditions and mostly share the same hinterland, with a high degree of overlap in their foreign trade partners. This inevitably leads to port competition. In order to avoid excessive competition caused by business overlap, ports are gradually moving towards a mutually beneficial model of macro-regulation by provincial port groups and division of labor according to provincial port groups.

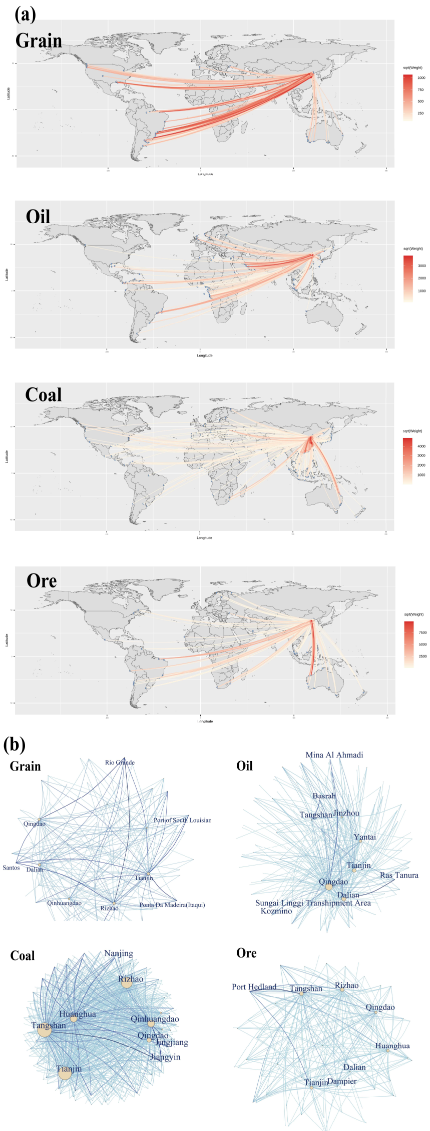

Figure 6. Global trade network of bulk cargo around Bohai Rim port cluster.

It is obvious that the ports around the Bohai Sea participating in global grain trade are greater in number than those in lumber transportation, with Tianjin Port, Rizhao Port, Qingdao Port, and Dalian Port being regional grain transshipment centers. They have high overlap with overseas ports in cooperation; for example, Ponta Da Madeira (Itaqui) Port in Brazil has established shipping links with all the Bohai Rim ports that operate in the grain transshipment business. High port overlap means fierce competition among ports. Appropriate competition is beneficial to efficient port operation, while excessive competition among ports in the same port cluster leads to inefficiency of agglomeration.

The oil product transportation centers around the Bohai Sea are concentrated in Qingdao Port, Tianjin Port, and Dalian Port. As shown in Figure 4, the first-tier oil product transport ports in the Bohai Rim port cluster, defined by throughput volume, have formed a triangular pattern among the four provinces, and oil product transportation business is widely distributed among the ports in the Bohai Rim area. This cargo transportation pattern is also clearly reflected in the foreign trade network map, as shown in the upper chart. The three main transportation hubs in the map overlap with the first-class oil product transportation ports, which are located in Liaoning Province, Shandong Province, and Tianjin Municipality (the ports in Tianjin and Hebei Province are grouped together as a port team due to their geographical proximity and similar main businesses). Although the oil product transportation trade network has a high degree of overlap, there is a clear hierarchical structure within the Bohai Rim port group; the two main international routes originate from Mina Al Ahmadi Port and Ras Tanura Port and connect Qingdao Port and Dalian Port, with overseas shipping also centered around the three main ports. The high degree of overlap in foreign trade partners and the clear hierarchical structure within the port group help the central ports in the region assist each other in bearing the pressure of oil products' movements in and out of port, achieving the efficient operation of the port cluster.

The coal foreign trade network map is much denser than those of oil products, grain, and wood, and its trading partners are mostly domestic ports, rather than overseas ports as is the case for other cargoes. The Bohai Rim region is close to China's northern coal production areas, and there are direct coal transportation lines to the ports; so, the coal foreign trade is mainly handled by the four Tianjin–Tangshan port group ports of Tianjin Port, Tangshan Port, Qinhuangdao Port, and Huanghua Port. The transshipment center has a clear spatial concentration, indicating that coal transport is mainly undertaken by the Tianjin–Tangshan port group, with other ports on the Bohai Sea coast involved less frequently. Of the 32 ports listed in the upper chart, 29 are Chinese ports, and the main shipping routes, excluding Zhapu Port, include Chinese ports, indicating that coal sea transportation trade mostly occurs within China.

The Tianjin–Tangshan agglomeration bears the main responsibility for coal transshipment business in the Bohai Rim area, and there is a hierarchical differentiation within the port agglomeration. The ports of Tangshan, Tianjin, and Rizhao are at the first level, serving as the regional hub ports, with Huanghua Port and Qinhuangdao Port at the second level, being the ports closest to the first-level hub ports in spatial terms. All these ports belong to the Hebei port group, and they can coordinate and cooperate with each other under the control of the group, according to the hierarchical division of labor.

The network of ore transportation in the Bohai Rim port cluster has formed a relatively tight network, indicating that ore transportation occurs extensively within the port group and involves small-scale transshipment within the Bohai Rim region. The chart delineates two circular port organizations, an inner ring mainly composed of ports in the Bohai Rim and reflecting their internal shipping routes, and an outer ring mainly composed of overseas ports, reflecting the external connections of the Bohai Rim port group in ore transportation. Overseas ports have established connections with almost all ports in the Bohai Rim, as shown in the map, and most ports in the Bohai Rim are connected to each other, indicating that the transportation of iron ore had formed a fairly dense transport network by 2019. In this transportation network, Tangshan Port, Rizhao Port, and Tianjin Port play the main transportation function, and the transfer of iron ore is mainly based within the Tianjin–Tangshan group, with the Qingdao–Rizhao group as an auxiliary, forming a relatively stable transport pattern.

From the global trade pattern map of bulk goods for the Bohai Rim's foreign trade, it can be seen that there are significant differences in the global trade patterns of different categories of goods. Crude oil, grain, and iron ore are completely imports, while lumber involves some export but not much, and the export destination is Japan and the Korean Peninsula. Coal has more exporting countries. Oil trade partners mainly include oil-producing countries in the Middle East, consistent with the world's main oil-producing regions. Grain trade mainly involves countries along the East Coast of Africa and the United States. Iron ore imports from Australia are the largest, similar to the oil trade, and the main sources of foreign trade are the countries that produce these goods. The partners in the wood trade are mainly concentrated in Southeast Asia, Australia, and on the west coast of South America.

The spatial distribution of the Bohai Rim port cluster's foreign trade partners has distinctive features, with Southeast Asia, Australia, and African countries being its main trading partners. There are fewer trade lines with Europe and North America, where developed countries are concentrated.

5. Discussion

5.1. Cluster Characteristics of the Bohai Rim Port Group

The clustering characteristics of the Bohai Bay port group reveal that large ports like Tangshan, Qingdao, and Tianjin dominate cargo throughput, while smaller ports play a more supportive role. This clear division of labor optimizes resource allocation and enhances ports' operational efficiency. Future comprehensive port construction can benefit from this clustering model by promoting coordinated development among different ports and avoiding resource wastage.

The Bohai Bay port group, influenced by market and policy factors, has formed regional port clusters based on provincial administrative divisions and geographical proximity, namely the Dalian port group, the Tianjin–Tangshan port group, and the Qingdao–Rizhao port group. Each group handles specific types of cargo, creating different growth patterns for oil, ore, coal, and grain. Intensive growth has been observed in newly developed port groups, where a central port sees rapid cargo volume increases in a short time. The edge port challenge effect shows that once the central port drives peripheral development, economic agglomeration decreases, and peripheral ports grow faster than those near the central port. The transfer mode is common in port development.

Administrative power guides the evolution of port clusters, with port investment and construction often used to promote regional economic development and achieve political goals. Port development is closely linked to urban development, with substantial government funding and trained professionals operating in port construction and management. While port depth and natural conditions form the basis of port development, policy regulation has a greater influence in practice. For example, although Huanghua Port has inferior natural conditions compared with Bangzhou Port, governmental designation as the export port for Shenfu coal has led to its rapid growth into one of the world's top ten cargo ports.

Currently, the management of Bohai Bay ports falls under the jurisdiction of relevant cities, but ports within the same city have been transferred to the overall control of port groups. This administrative division still limits port construction performance. Tianjin Port's rapid development under policy support and the simultaneous development of Tianjin and Hebei Ports, leading to intense competition, highlight the decisive role of administrative power in port development. Qingdao Port and its surrounding ports have swiftly developed through technological innovation and international vision, becoming Northeast Asia's largest port and international logistics hub, continuously enhancing their competitiveness in global trade.

5.2. Network Development and Future Insights for Major Bulk Cargo Ports in Bohai Rim

The Bohai Bay port group exhibits significant differences in transportation networks for various types of bulk cargo. For instance, oil transportation is concentrated in Qingdao and Dalian Ports, forming a clear core–periphery structure. Ore transportation has shifted from Qingdao's dominance to Tangshan's rise, showcasing dynamic competition among ports. Coal transportation is primarily centered in the Tianjin–Tangshan port group, indicating its monopolistic position in bulk cargo transportation. These differences highlight the distinct impacts of transportation demands and market dynamics on port development. Future construction of bulk cargo ports should consider the characteristics and market demands of different cargo types, developing targeted construction and development strategies to enhance ports' specialization and competitiveness.

The Bohai Bay ports experienced varying degrees of decline in cargo throughput from 2017 to 2019 due to the US–China trade war, with ore seeing a greater decrease than oil, coal, or grain, and oil reacting the fastest. In 2017, oil showed a significant turning point, while coal, ore, and grain declined the following year. Ore transportation is highly influenced by macroeconomic factors such as regional economic integration, government policies, and related maritime industry support, while the oil market is more sensitive to environmental changes.

First-tier and fourth-tier ports are relatively stable, with minimal fluctuations in their growth rates. Ports like Qingdao and Tangshan, as first-tier ports, have become regional central ports with substantial cargo volumes, maintaining their core positions over the long term. Despite spatial shifts in port transportation structures over the past two decades (e.g., the ore transportation center moving from Qingdao and Rizhao to Tangshan), these ports have established high reputations and long-term stable hinterlands. Even with changes in transportation product structures, exchanges and transfers between first-tier central ports have usually occurred without affecting the core positions within the port group.

Fourth-tier ports such as Weifang and Dongying, despite being located at the geometric center of the Bohai Bay port group, remain marginalized due to limited port depth and small cargo volumes. These ports have lower risk resistance, but their small cargo volumes make them less susceptible to impacts from financial crises and other domestic and international events. Second and third-tier ports have higher fluctuations in growth rate, as they rely on the development of core ports within the group, with limited radiation effects from those core ports. Consequently, competition for overflow functions from core ports becomes the main content of second and third-tier port competition. These ports, with smaller cargo volumes and moderate port scales, generally have average risk resistance, making them more vulnerable to market fluctuations and disasters in China.

The differences in network development among major bulk cargo ports demonstrate the complexity and diversity of port development. Future bulk cargo port construction should fully consider natural conditions and economic hinterlands, actively leveraging policy support and innovative technologies to enhance international competitiveness and risk resistance.

5.3. China's Bulk Cargo and Global Patterns

China's bulk cargo ports occupy a significant position globally, with the Bohai Bay port group standing out in global cargo throughput rankings. As ports like Tangshan and Rizhao rise, Chinese ports' competitiveness in the global market continues to strengthen. Particularly in grain and coal transportation, Chinese ports have established close cooperative relationships with major global ports, showcasing their crucial role in the global supply chain. Despite a decline in cargo throughput from 2017 to 2019 due to the US–China trade war, Qingdao Port consistently performed well in international business, demonstrating its competitiveness in global trade. Qingdao Port, as Northeast Asia's largest port and international logistics hub, has successfully adapted to market changes and environmental challenges through advanced technology and international vision. Qingdao Port's pioneering application of 5G technology in cargo handling has significantly improved clearance efficiency and transportation capacity, enhancing its position in global trade.

This global pattern reflects the strong operational capabilities of Chinese ports and underscores China's vital role in global trade. Looking forward, China should continue to strengthen international cooperation, enhance port intelligence and greening levels, and respond to changes in the global trade environment. The Bohai Bay port group's increasing importance in global bulk cargo transportation provides valuable insights for other regions. Chinese bulk cargo ports should further improve technological levels and management capabilities, strengthen international cooperation, and consolidate their leading position in global trade.

5.4. Limitations and Prospects

Despite the significant achievements of the Bohai Bay port group over the past decades, several challenges and limitations remain. First, the issues of competition and coordination among ports need further resolution, particularly between Tianjin and Hebei ports. Second, the natural conditions and infrastructure of some ports, such as Weifang and Dongying, limit their further development. Additionally, while policy support has been crucial in promoting port development, over-reliance on policy may lead to imbalances and long-term sustainability issues.

Looking ahead, the Bohai Bay port group should continue to enhance technological innovation capabilities, optimize port management and operational models, and increase international competitiveness and risk resistance. Strengthening cooperation and coordination among ports, achieving resource sharing, and complementing advantages are essential. Additionally, leveraging advanced technologies such as big data and artificial intelligence to improve port intelligence and automation levels is crucial. Through continuous innovation and optimization, the Bohai Bay port group will continue to play a significant role in global bulk cargo transportation and provide valuable experiences and insights for global port development.

6. Conclusions

This paper examines the evolving transportation patterns within the Bohai Rim port cluster, analyzing the throughput of four major commodities—oil, ore, coal, and grain—across 13 ports from 1999 to 2019. This study identified shifts in port cargo transport patterns and their influencing factors, revealing that the Bohai Rim's transport network has transformed from its previous triangular configuration (Dalian group, Tianjin–Tangshan group, and Qingdao–Rizhao group) to a current dual-core structure dominated by Tangshan and Qingdao Ports. Each of the four bulk commodities displays unique transport network characteristics, with the Tianjin–Tangshan group primarily handling coal, grain, and ore for domestic trade (e.g., north–south coal transport), while the Qingdao–Rizhao group, centered on oil, primarily supports international trade.

Ports within the cluster were categorized into four tiers based on throughput. While Tier 1 and Tier 4 ports hold relatively stable positions, Tiers 2 and 3 experience considerable variability, marked by intense competition and greater sensitivity to external factors. The tiered structure reflects the dominance of top-tier ports like Qingdao and Tianjin in dry bulk traffic, while fourth-tier ports assume supportive roles. Differences within this hierarchical structure contribute to a pattern of fluctuating development within the port group network, where both competition and cooperation shape the cluster's evolution.

The study achieves its primary goals by providing a comprehensive analysis of both the competitive dynamics and the cooperative relationships among Bohai Rim ports, as well as the unique transport patterns associated with different bulk commodities. Additionally, the network analysis accurately depicts the topological structure of the cargo transport network, clarifying the roles of individual ports and their interactions within the cluster. By investigating the impact of policy guidance and government investment on port development, this study also offers valuable insights into the forces driving growth and change in the cluster.

Overall, this research effectively meets its objectives, contributing to a nuanced understanding of the Bohai Rim port cluster's evolution and providing a framework for assessing similar port clusters under changing economic and trade conditions.

Author Contributions: Conceptualization, F.Y.; methodology, F.Y. and Y.X.; data curation, F.Y. and Y.X.; writing—original draft preparation, F.Y.; writing—review and editing, Y.X. and C.W.; visualization, Y.X.; supervision, C.W. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The original contributions presented in the study are included in the article, and further inquiries can be directed to the corresponding authors.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Cao, Y.; Cao, W.; Jin, S. The formation and evolution mechanism of China's coastal container port system. *Acta Geogr. Sin.* **2003**, *58*, 424–432.
2. Lau, Y.Y.; Ducruet, C.; Ng, A.K.Y.; Fu, X. Across the waves: A biliometric analysis of container sipping research since the 1960s. *Marit. Policy Manag.* **2017**, *44*, 667–684. [CrossRef]
3. Rimmer, P.J. The changing status of New Zealand seaports 1853~1960. *Ann. Assoc. Am. Geogr.* **1967**, *57*, 88–100. [CrossRef]
4. Chen, Y.; Yao, T. The New Concept of Fifth Generation Port and Navigation Engineering. *IOP Conf. Ser. Earth Environ. Sci.* **2020**, *619*, 012067.
5. Slack, B. Intermodal transportation in North America and the development to Finland load centers. *Prof. Geogr.* **1990**, *42*, 72–83. [CrossRef]
6. Barke, M. *Transport and Trade*; Oliver & Boyd: Edinburgh, UK, 1986.
7. Cullinane, K.; Wang, T.F. The technical efficiency of container ports: Comparing data envelopment analysis and stochastic frontier analysis. *Transp. Res. Part A-Policy Pract.* **2006**, *40*, 354–374. [CrossRef]
8. Melas, K.D.; Faitatzoglou, A.; Michail, N.A.; Artemiou, A. Volatility Spillovers among the Major Com-modities: A Review. *J. Risk Financ. Manag.* **2024**, *17*, 365. [CrossRef]
9. Notteboom, T.; Winkelmans, W. Structural changes in logistics: How will port authorities face the challenge? *Marit. Policy Manag.* **2001**, *28*, 71–89. [CrossRef]
10. Bandyopadhyay, A.; Rajib, P. The asymmetric relationship between Baltic Dry Index and commodity spot prices: Evidence from nonpara-metric causality-in-quantiles test. *Miner. Econ.* **2023**, *36*, 217–237. [CrossRef]
11. Ducruet, C.; Notteboom, T.E.; De Langen, P.W. Revising Inter-Port Relationships under the New Economic Geography Research Framework. In *Ports in Proximity*; Routledge: London, UK, 2016; pp. 11–27.
12. Feng, H.; Grifoll, M.; Zheng, M. From a feeder port to a hub port: The evolution pathways, dynamics and perspectives of Ningbo-Zhoushan port (China). *Transp. Policy* **2019**, *76*, 21–35. [CrossRef]
13. Peng, Y.; Li, Z.; Duan, W.; Li, X.; Bao, Q. Evolution of the hinterlands of eight Chinese ports exporting to Europe under the Polar Silk Road: Three hypothetical scenarios. *Ocean Coast. Manag.* **2021**, *205*, 105549. [CrossRef]
14. Ren, M.; Yang, B. Analysis of current conditions of port development in China—Also on Shanghai International Shipping Center. *ACTA Geogr. Sin.* **1998**, *53*, 193–201.
15. Slack, B.; Wang, J.J. The challenge of peripheral ports: An Asian perspective. *GeoJournal* **2003**, *56*, 159–166. [CrossRef]
16. Wang, A.; Kuang, G. The evolution and competition situation of container port cluster system in China. *Econ. Geogr.* **2014**, *34*, 92–99.
17. Wang, J.J.; Slack, B. The evolution of a regional container port system the Pearl River Delta. *J. Transp. Geogr.* **2000**, *8*, 263–275. [CrossRef]
18. Wang, L.; Lau, Y.; Su, H.; Zhu, Y.; Kanrank, M. Dynamics of the Asian shipping network in adjacent ports: Comparative case studies of Shanghai-Ningbo and Hong Kong-Shenzhen. *Ocean Coast. Manag.* **2022**, *221*, 10627. [CrossRef]
19. Xu, Q.; Huang, T.; Chen, J.; Wan, Z.; Qin, Q.; Song, L. Port rank-size rule evolution: Case study of Chinese coastal ports. *Ocean Coast. Manag.* **2021**, *211*, 105003. [CrossRef]
20. Zhang, Q.; Yan, K.; Yang, D. Port system evolution in Chinese coastal regions: A provincial perspective. *J. Transp. Geogr.* **2021**, *92*, 103031. [CrossRef]
21. Zheng, C.; Zou, H.; Gu, Y. Research on the development strategy of harbor service industry based on the intergenerational evolution of ports -- A case study of Ningbo Port. *Sci. Technol. Manag. Res.* **2014**, *2*, 53–57.
22. Wang, J.J. A container load center with developing hinterland: Case study of Hongkong. *J. Transp. Geogr.* **1998**, *6*, 187–201. [CrossRef]

23. Lu, K.; Wu, W.; Yu, H.; Su, F. Global container port network linkages and topology in 2021. *Sensors* **2022**, *22*, 5889. [CrossRef] [PubMed]
24. Liu, Q.; Yang, Y.; Ke, L.; Ng, A.K. Structures of port connectivity, competition, and shipping networks in Europe. *J. Transp. Geogr.* **2022**, *102*, 103360. [CrossRef]
25. Li, L.; Wei, C.; Liu, J.; Chen, J.; Yuan, H. Assessing port cluster resilience: Integrating hypergraph-based modeling and agent-based simulation. *Transp. Res. Part D Transp. Environ.* **2024**, *136*, 104459. [CrossRef]
26. Luo, M.; Chen, F.; Zhang, J. Relationships among port competition, cooperation and competitiveness: A literature review. *Transp. Policy* **2022**, *118*, 1–9. [CrossRef]
27. Chang, H.H.; Huang, W.C. Application of a quantification SWOT analytical method. *Math. Comput. Model.* **2006**, *43*, 158–169. [CrossRef]
28. Kuby, H.M.; Reid, N. Technological change and the concentration of the U.S. general cargo port system: 1970–88. *Econ. Geogr.* **1992**, *68*, 272–289. [CrossRef]
29. Cao, Y.; Jiang, Z.; Chen, H. The evolution course and mechanism of the port system along the Yangtze River. *Prog. Geogr.* **2015**, *34*, 1430–1440.
30. Fedi, L.; Faury, O.; Regot-Muller, P.; Montier, N. COVID 19 as a catalyst of a new container port hierarchy in Mediterranean Sea and Northern Range. *Marit. Econ. Logist.* **2022**, *24*, 747–777. [CrossRef]
31. Notteboom, T.E. Concentration and load centre development in the European container port system. *J. Transp. Geogr.* **1997**, *5*, 99–115. [CrossRef]
32. McCalla, R.J. From St John's to Miami: Containerisation at Eastern Seaboard Ports. *GeoJournal* **1999**, *48*, 21–28. [CrossRef]
33. Wei, C.; Liu, X.; Zhang, L.; Wan, Y.; Huang, G.; Lu, Y.; Zhang, X. Resilience analysis of global agricultural trade. *Environ. Plan. B Urban Anal. City Sci.* **2024**, *51*, 1003–1006. [CrossRef]
34. Chen, F.Y.; Hu, Z.H. Analysis of shipping network of Southeast-Asian route along maritime Sil Road based on complex networks. *J. Shanghai Univ. Nat. Sci. Ed.* **2016**, *22*, 804–812.
35. Dadashpoor, H.; Taheri, E. Port city interface dynamics for the Bandar Abbas port, Iran. *GeoJournal* **2023**, *88*, 4645–4670. [CrossRef]
36. Hayuth, Y. Rationalization and concentration of the U·S· container port system. *Prof. Geogr.* **1988**, *40*, 279–288. [CrossRef]
37. Hoyle, B.; Charlier, J. Inter- port competition in developing countries: An East African case Study. *J. Transp. Geogr.* **1995**, *13*, 87–103. [CrossRef]
38. Kamble, S.S.; Raoot, A.D.; Khanapuri, V.B. Improving port efficiency: A comparative study of selected ports in India. *Int. J. Shipp. Transp. Logist.* **2010**, *2*, 444–470. [CrossRef]
39. Singh, A.; Chhetri, P.; Padhye, R. Modelling inter-firm competitive rivalry in a port logistics cluster: A case study of Melbourne, Australia. *Int. J. Logist. Manag.* **2022**, *33*, 455–476. [CrossRef]
40. Haezendonck, E.; Langenus, M. Integrated ports clusters and competitive advantage in an extended resource pool for the Antwerp Seaport. *Marit. Policy Manag.* **2019**, *46*, 74–91. [CrossRef]
41. Xu, J.Y. *Modern Port and Urban Development: The Case of Guangzhou*; Sun Yat-Sen University: Guangzhou, China, 2001.
42. Wang, C.; Ducruet, C. Theoretical model of container port system and its empirical research in Yangtze River Delta. *Geogr. Res.* **2011**, *30*, 397–410.
43. Cao, Y.; Li, H.; Chen, W. The spatial structure and the competition pattern of the container port system of China. *Acta Geograph. Sin.* **2014**, *59*, 1020–1027.
44. Guo, L.B.; Li, J.; Xing, W. Port Co-opetition Research in Bulk and Container Business. *J. Transp. Syst. Eng. Inf. Technol.* **2017**, *17*, 189–196.
45. Deng, Z.; Duan, W.; Zhou, Y.T. Analysis of Port Transportation Functions Based on the Structure of Cargo Types. *Appl. Spat. Anal. Policy* **2023**, *16*, 437–459. [CrossRef]
46. Xu, Y.; Yan, X. Review of west study on modern port and urban-regional development. *Hum. Geogr.* **2001**, *16*, 28–33.
47. Huo, W.W.; Zhang, W.; Chen, P.S.-L. Recent development of Chinese port cooperation strategies. *Res. Transp. Bus. Manag.* **2018**, *26*, 67–75. [CrossRef]
48. Nyunt, H.H.K.; Kim, H.D. A Study on the Efficiency of Container Ports in the Bay of Bengal Area. *J. Korea Port Econ. Assoc.* **2020**, *36*, 41–58. [CrossRef]
49. Xu, Y.; Yan, X.; Xu, X. Study on the Multi-functional Development of Modern Port: The Case of Guangzhou. *Econ. Geogr.* **2001**, *21*, 235–239+243.
50. Feng, H.X.; Grifoll, M.; Yang, Z.Z.; Zheng, P.J.; Martion-Mallofre, A. Visualization of container throughput evolution of the Yangtze River Delta multi-port system: The ternary diagram method. *Transp. Res. Part E-Logist. Transp. Recew* **2020**, *142*, 102039. [CrossRef]
51. Tagawa, H.; Kawasaki, T.; Hanaoka, S. Difference in port cooperation between motivations: Cooperation for regional welfare and for competition. *Marit. Transp. Res.* **2022**, *3*, 100075. [CrossRef]