A TERNARY DIAGRAM APPROACH TO INVESTIGATE THE COMPETITION WITHIN THE BOHAI SEA RIM MULTI-PORT GROUP

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Keywords

Ternary diagram; Shipping center; Bohai Rim; Container; Port evolution.

Abstract

Bohai Rim is the third "growth pole" in China's economic development. Tianjin Port, Dalian Port, and Qingdao Port in the Bohai Rim multi-port system compete fiercely for the position of the shipping center in northern China. Compared with the ternary diagram method, the comprehensive concentration index (CCI), Lerner index (LI), and spatial shift-share analysis (SSSA) are applied to investigate the concentration, inequality, and competitive dynamics of the Bohai Rim multi-port system during 1981–2021. This contribution aims to analyze the evolution path and dynamic mechanism of the Bohai Rim multi-port system. The method allows the development to be divided into three stages: the dominant stage of Tianjin Port from 1981–1990, the stage of efficiency competition from 1991–1996, and the ascending stage of Qingdao Port from 1997–2021. The results indicate that: i) the concentration of the Bohai Rim multi-port system is low, and balanced growth is ensured in the non-monopolistic competitive environment; ii) the internal competitiveness of the Bohai Rim multi-port system has gradually shifted from Tianjin Port to Qingdao Port, while the container transport in Dalian Port has slowly developed. iii) the container throughput of Dalian Port has declined since 2015, with weak competitiveness. The results suggest that Qingdao Port should be developed into the northern China shipping center. The method applied here may also be useful for similar multi-port systems elsewhere.

1 INTRODUCTION

Located in northern China, the Bohai Rim port group is the main cargo seaport in the Northeast, North China, Northwest, and East China. Geographically, the Bohai Rim Area is located in the center of the Northeast Asian economic circle, radiating different economic regions and countries in different directions, with unique regional advantages (Zhang et al., 2022). From the perspective of composition, the Bohai Rim Area is composed of three sub-economic zones, namely Beijing-Tianjin-Hebei, Liaodong Peninsula, and Shandong Peninsula (see **¡Error! No se encuentra el origen de la referencia.**). It is a composite economic zone that accounts for about 35.4% of China's GDP (Jin Lianjie, 2022). With the development of the regional economy, the container throughput of the Bohai Rim multi-port system is growing rapidly.

Fig. 1 Location of Bohai Rim multi-port system and map of gateway ports in Northeast Asia

In 2021, the container throughput of the Bohai Rim multi-port system accounted for 25% of the national total throughput. However, the development of the Bohai Rim multi-port system is relatively backward compared to the Yangtze River Delta multi-port system and the Pearl River Delta multi-port system, which account for 37% and 31% of the national container throughput respectively. Due to the fierce competition from foreign ports such as Pusan, Kobe, and Yokohama, the ports in the Bohai Rim multi-port system are in danger of becoming foreign feeder ports (Meng, 2011). The establishment of a northern shipping center can improve the competitiveness of the Bohai Rim multi-port system. At the same time, the Tianjin Port, Dalian Port, and Qingdao Port in the Bohai Rim multi-port system are competing for the shipping center in northern China, resulting in disorderly competition and waste of resources. As an important part of the economic growth in northern China, studying the evolution of the status of Tianjin Port, Dalian Port, and Qingdao Port in the Bohai Rim multi-port system, and a port was selected from Tianjin Port, Dalian Port, and Qingdao Port as the major container trunk port and a northern China shipping center, which is of great significance for realizing regional port integration and promoting sustainable development of the regional economy.

The formation and evolution of the port system have been a research focus for scholars since the 1960s. Scholars have developed many classical models to systematically study the evolution of the port system (Bird

(1963); Taaffe E (1963); RIMMER (1967); Hayuth (1981); Notteboom and Rodrigue (2005)). At the same time, many scholars have studied the evolution of port systems in different countries and regions, such as Latin America and the Caribbean (Gordon Wilmsmeier et al. (2014); Gordon Wilmsmeier and Jason Monios (2016);)), Maghreb (Fatima Mohamed-Chérif and César Ducruet (2016);), Mediterranean (Manel Grifoll et al., 2018), Korea (Dong-Wook Song and Sung-Woo Lee, 2017)) and Mexico (Juan Carlos Villa, 2017), etc. With the rapid growth of China's economy, the development of Chinese ports has made great progress. By 2021, Chinese ports have occupied seven of the world's top ten container ports, and the evolution process of Chinese ports has attracted more and more attention. Liu et al. (2013), Song (2002), and Yang et al. (2019) considered the development process of the Pearl River Delta and Hong Kong Port respectively. Cullinane et al. (2005) and Wang and Yeo (2019) respectively analyzed the evolution of the status of Shanghai Port and Ningbo Port in the Yangtze River Delta multi-port system. Due to the increasingly significant impact of ports on local economies, local governments are blindly expanding ports, while the global economy is sluggish and port resources are saturated, leading to increasingly fierce disorderly competition between regional ports (Wu and Yang, 2018). Therefore, great attention is paid to sustainable regional port governance (Lam. et al., 2013). Establishing a shipping center, determining a hub port, and reducing disorderly competition are a form of regional port governance mode. For instance, taking the Shanghai International Shipping Centre as an example, Wang. and Slack. (2004) researched China's port governance, and believed that establishing a shipping center, hub ports and branch ports would reduce disorderly competition between ports with similar functions and enhance the overall competitiveness of the port system; Huang (2009) discussed how developing an international shipping centre in Shanghai can stimulate the hinterland economy and improve the global shipping network.

This literature review reveals that there is currently a wealth of well-founded research on the evolutionary model of port systems. Research on the Chinese port system has predominantly focused on the Yangtze River Delta and the Pearl River Delta, while the port system around the Bohai Rim Area has received relatively little attention. This paper analyzes the competition and cooperation dynamics among Tianjin Port, Dalian Port, and Qingdao Port, examining aspects of concentration, inequality, and competition by Comprehensive Concentration Index (CCI), Lerner Index (LI), Spatial Shift Share Analysis (SSSA), and the ternary diagram separately. Providing a comprehensive overview of the evolutionary process of the Bohai Rim multi-port system and studies the evolution of the northern China shipping center on this basis.

Following the introduction, Section 2 introduces the data used and the methods of the ternary diagram. Section 3 reports the results, followed by a discussion of the different stages of development and their underlying reasons. Section 4 summarizes the role evolution process of Tianjin Port, Dalian Port, and Qingdao Port in the Bohai Rim multi-port system and analyzes the final winner of the northern China shipping center contest.

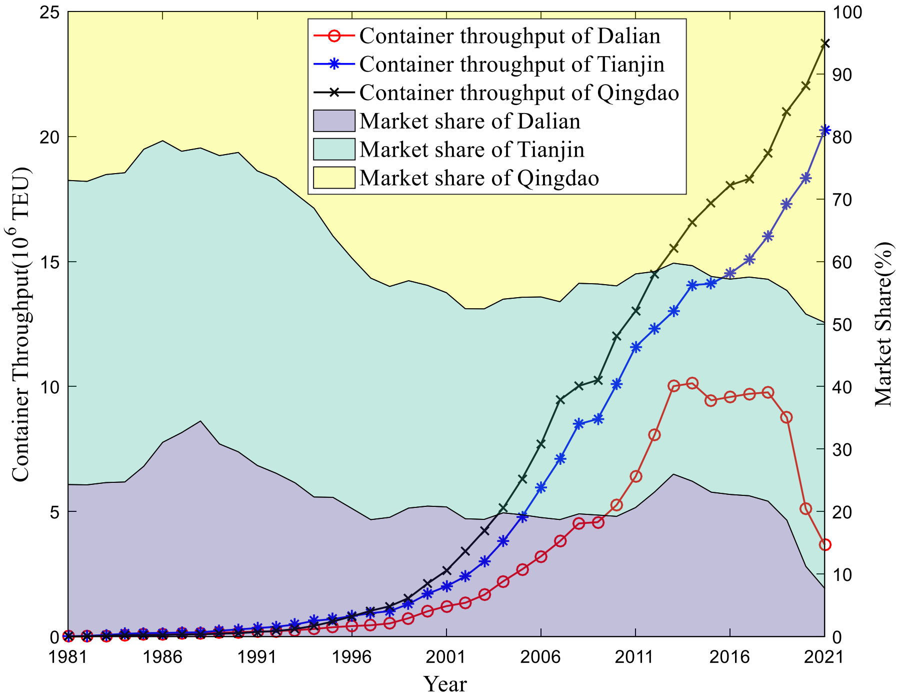
2 DATA AND METHODOLOGY

2.1 Data

The data used in this paper (see Figure 2), the container throughput for 1990-2018, comes mainly from the China Port Yearbook; that of 2019–2021 is obtained from public information on the website of the Chinese Ministry of Transport. The authors compile data for 1981–1989 from various sources. Figure 2 shows the traffic evolution of the Bohai Rim ports during the period 1981–2021 period. We find that the container throughput of Qingdao Port and Tianjin Port represents sustainable growth. The market share of Qingdao Port began to surpass that of Tianjin in 1997, while the decline of Dalian Port is obvious. Container throughput has not exceeded 10 million TEU since the first negative growth in 2015.

Fig. 2 Container throughput and traffic share of Dalian Port, Tianjin Port, and Qingdao Ports from 1981 to

2021.



2.2 Methods

2.2.1 Comprehensive Concentration Index (CCI)

The CCI was first built by Horvarth in 1970 (Horvarth, 1970), is an indicator that represents the market share of the highest-ranked port in the port group, and the market share of the top port is directly proportional to CCI. CCI is specifically represented as:

$$CCI = TEU_1 + \sum_{i=2}^{n} TEU_i^2(1 + (1 - TEU_i)) \quad (1)$$

The number of ports is expressed as i to n, and TEU_1 is the port with the highest container throughput. When the value of CCI approaches 1, the port with the largest container throughput is at an absolute advantage in a multiple port system. When it is less than 0.5, the critical role of the port decreases as the CCI value decreases.

2.2.2 Spatial Shift Share Analysis (SSSA)

Notteboom, T. E. (1997) employed SSA to assess the multiple port system, and the definitions for variables S and A are elucidated as follows:

$$SHIFT_j = \frac{\frac{TEU_{jt1}}{\sum_{j=1}^{m} TEU_j} - \frac{TEU_{jt0}}{\sum_{j=1}^{m} TEU_j}}{\frac{TEU_{jt0}}{\sum_{j=1}^{m} TEU_j}} \quad (2)$$

where $SHIFT_j$ is the total shift of port j from time t_0 to t_1, and m refers to the number of ports.

SSA has traditionally focused on studying changes in a specific region over time. However, the significance of spatial structures and the geographical location of a given region as influential factors are often ignored in the analysis. However, there exists a discernible correlation between regions within the same geographical area. Isard, W. (1960) emphasizes the importance of examining a particular region in the context of its neighbouring regions since changes in neighbouring regions can impact the dynamics of the target region. In fact, no target area operates independently of other regions, and the economic performance of a specific region can be significantly influenced by the economic environment of the surrounding areas. By incorporating spatial geographic location and using regional GDP as an indicator of geographic economics, an extended Spatial Shift Share Analysis (SSSA) is presented as follows:

$$SSHIFT_j = \frac{\frac{TEU_{jt1}}{\sum_{j=1}^{m} TEU_j} - \frac{TEU_{jt0}}{\sum_{j=1}^{m} TEU_j}}{\frac{TEU_{jt0}}{\sum_{j=1}^{m} TEU_j}} * \left| \frac{\frac{G_{jt1}}{\sum_{j=1}^{m} G_j} - \frac{G_{jt0}}{\sum_{j=1}^{m} G_j}}{\frac{G_{jt0}}{\sum_{j=1}^{m} G_j}} \right| \tag{3}$$

where G_j represents the geographical weight indicator of port j, $SSHIFT_j$ is the geographical shift of port j from time t_0 to t_1, and m refers to the number of ports.

2.2.3 Lerner Index (LI)

Lerner Index (LI) reflects the discretion and inequality of the multi-port system, which varies between 0 to 1, and the value of LI is inversely proportional to the dispersion of the market. If n ports are of the same scale, n approaches infinity, and LI tends to 0.

$$LI = \frac{P-MC}{P} = 1 - \frac{1}{|\varepsilon|} \tag{4}$$

where P is the container throughput, MC is the marginal cost, ε is the L is the price demand elasticity.

A larger value of "L" indicates greater competitiveness among ports, a lower likelihood of price markups, and marginal profits for ports, reflecting a lower degree of monopoly. To determine the price elasticity of demand for container transportation demand, the indicators "container throughput (TEU)" and "market share (A)" are selected to replace the basic variables of demand and price variables in container transportation. The logarithmic model is used to empirically analyze the relationship between throughput and the interval proportion as follows:

$$\ln TEU_{it} = a_i + b_i \ln \frac{TEU_{it}}{\sum_{i=1}^{n} TEU_{it}} + u_i \tag{5}$$

Differentiating formula 1, the following formula can be obtained:

$$b_i = \frac{dTEU_{it} * \frac{TEU_{it}}{\sum_{i=1}^{n} TEU_{it}}}{d\frac{TEU_{it}}{\sum_{i=1}^{n} TEU_{it}} * TEU_{it}} \tag{6}$$

The regression coefficient b_i is the demand price elasticity of the container throughput in the i port.

2.2.4 Basic framework of the ternary diagram

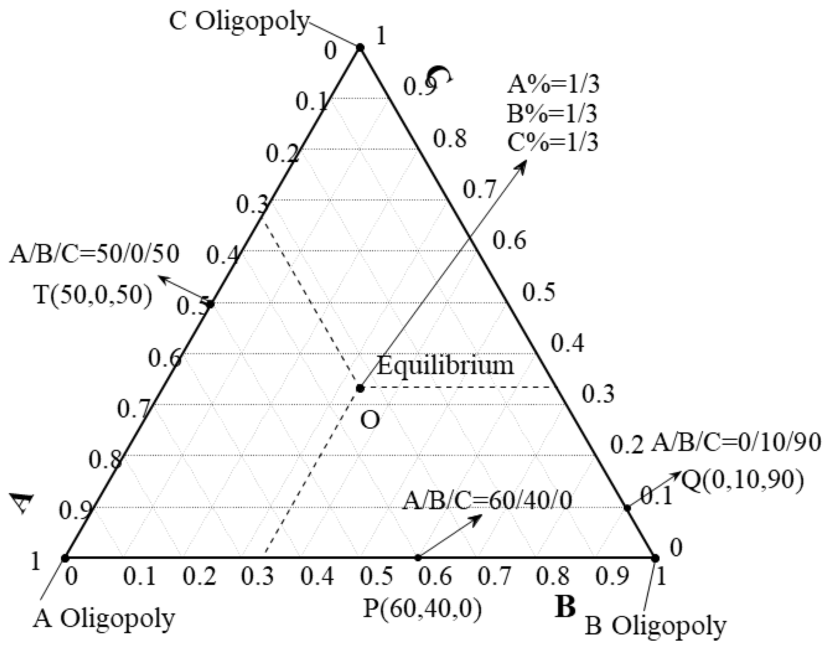
A ternary diagram is a visualization tool, Feng et al. (2020) first introduced the ternary diagram into the field of port and shipping research. Its basic frame consists of points and lines. Each point in the ternary graph is composed of three components A, B, and C (see **¡Error! No se encuentra el origen de la referencia.**), and A+B+C=1.

The points in a ternary diagram that are located at angles, sides, and barycenters have special meanings. The coordinates of the three corners in the ternary diagram are (0, 0, 1), (1, 0, 0) and (0, 1, 0), which means that the point is composed of only one component, that is, the market of the multi-port system is completely monopolized by one port (see **¡Error! No se encuentra el origen de la referencia.**).

The point on the side of the ternary diagram means that the point is composed of two components, that is, the market share of the port group is composed of two ports. For instance, when the point is on the side of AB, the market share of the port group only consists of ports A and B.

When the point O is at the center of the barycenter, the coordinate is (1/3, 1/3, 1/3), which means that the market share of the multi-port system is equally divided among the three ports, that is, there is absolute balance and the maximum competition in the multi-port system.

Fig. 3 Corners, sides, and barycentre.



2.3 Ternary diagram

The evolution index of the multi-port system is proposed by Fu, Y., Lin, Q., Grifoll, M., Lam, J. S. L., & Feng, H. (2023), that is, the concentration will be calculated by CCI and the Maximum Value of the Component (MVC), the inequality will be computed with LI and the Distance of a Point to the Barycenter (DPB), and the SSSA add the Change of the Three Components (CTC), are proposed to describe the competition of the multi-port system.

The MVC calculation formula is:

$$MVC = \max(A, B, C) \tag{7}$$

where A, B, and C are the market shares of ports A, B, and C, respectively. When the value of Port A exceeds 0.5, it means that the port has the largest market share, exceeding 50%. Therefore, the market is expected to be dominated by Port A. When the market share of each port is less than 50%, it is in the "Efficiency Competition" area, which means that no port can absolutely dominate the market.

The DPB calculation formula is:

$$\text{DPB}=\sqrt[2]{(\text{A}-1/3)^2+(\text{B}-1/3)^2+(\text{C}-1/3)^2} \tag{8}$$

where A, B, and C are the market shares of the three ports, respectively. The Normalized DPB (NDPB) is introduced more intuitively to see the change in the inequality of the multi-port system. The NDPB is calculated according to the following formula:

$$NDPB = \frac{\sqrt{6}}{2} \times DPB \tag{9}$$

The value range of NDPB is [0, 1]. When the NDPB is greater than 0.5, it means that the inequality of the multi-port system is high, otherwise, it is low.

The CTC calculation formula is:

$$CTC = (CTC_{\mathrm{A}}, CTC_{B}, CTC_{\mathrm{C}}) = (\Delta A, \Delta B, \Delta C) \tag{10}$$

where ΔA, ΔB, and ΔC reflect the change of market shares of port A, port B, and port C, respectively. ΔA, ΔB, and ΔC are obtained by the following formula:

$$\begin{cases} \Delta A = \mathrm{A}_{t+1} - \mathrm{A}_{t} \\ \Delta B = \mathrm{B}_{t+1} - \mathrm{B}_{t} \\ \Delta C = \mathrm{C}_{t+1} - \mathrm{C}_{t} \end{cases} \tag{11}$$

Where t is the time, At, Bt, and Ct are the market shares of ports A, B, and C at time t, respectively, and At+1, Bt+1, and Ct+1 are the market shares of ports A, B, and C at time t+1, respectively.

3 RESULTS

This section presents the analysis results of the ternary graph indicators, namely MVC, DPB, and CTC, as well as three methods including CCI, LI, and SSSA. The effectiveness of the method is verified by comparing MVC and CCI, DPB and LI, and CTC and SSSA.

3.1 MVC and CCI

As shown in **¡Error! No se encuentra el origen de la referencia.**, from 1981-1996, the container throughput of Tianjin Port was the largest in the Bohai Rim multi-port system; the container throughput of Qingdao Port surpassed that of Tianjin Port in 1997, making Qingdao Port the port with the largest container market share among the Bohai Rim multi-port system. **¡Error! No se encuentra el origen de la referencia.** (right) shows the MVCs from 1981 to 1990 fell in or were close to the "Tianjin Port Dominating" area; since 1991, Qingdao Port's share of the container market has steadily increased year after year. In 1991-1996, the value of MVCs was in the "Efficiency Competition" area. Therefore, this study divides the evolution stage of the Bohai Rim multi-port system into "the stage of Tianjin's leading (1981-1990)", "the stage of efficiency competition (1991-1996)", and "the stage of Qingdao's rising (1997-2021)".

Fig. 4 CCI (left) and MVC (Right) of the Bohai Rim multi-port system, 1981-2021.

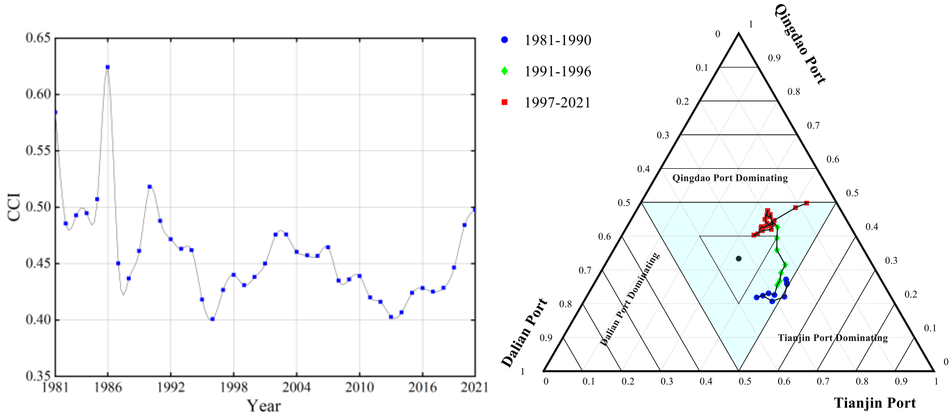


Figure 4 (left) shows that the CCI of the Bohai Rim terminal system has declined steadily from 0.486 to 0.401 between 1981 and 1996, indicating that the market moved from having an absolute advantage in ports to a loss in core key ports. After a period of stable increase from 1996 to 2003, the CCI gradually declined from below 0.403. Since 2013, the CCI value has been rapidly approaching the value of 0.5 in 2021, indicating that the development trend of a certain port that is on the verge of having an absolute advantage is becoming more and more obvious.

¡Error! No se encuentra el origen de la referencia. (right) plots the evolutionary pathways of container throughput in Dalian, Tianjin, and Qingdao from 1981 to 2021. From 1981 to 1990, the values of MVCs slowly decreased from 0.49 to 0.46. During 1991-1996, the MVCs declined rapidly from 0.48 to 0.40. Since 1997, the MVCs have been slowly increasing from 0.43 to 0.50 in 2021.

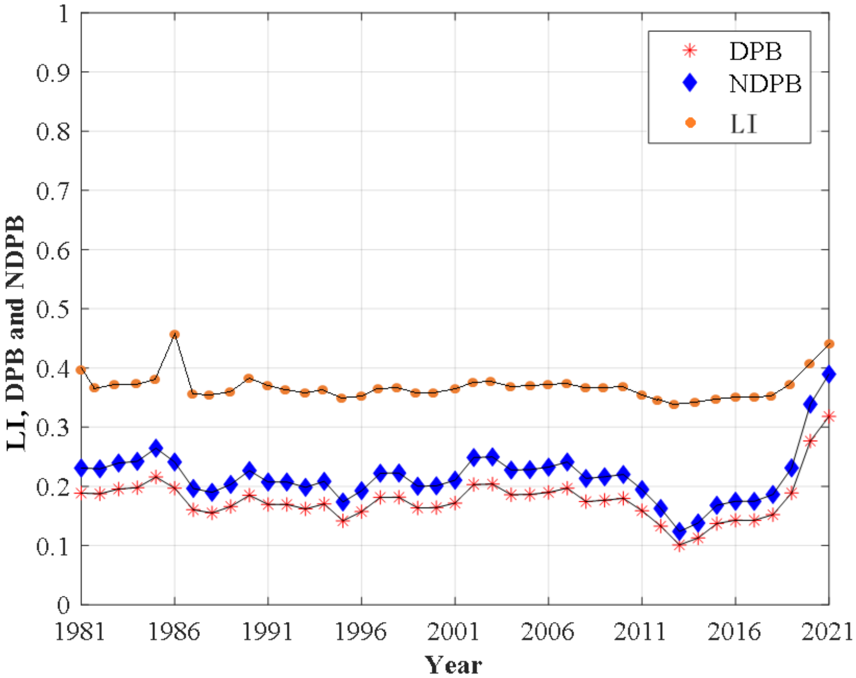
As shown, the values of MVCs were close to or equal to 0.5 in 1981-1983, indicating that Tianjin Port was in a dominant position during this period. The MVCs began to slowly decline in 1984 to 0.46 in 1990, indicating that although Tianjin Port is no longer in the leading position, its market share is still the largest. During the years 1991 to 1996, the MVCs were always below 0.5, meaning that the competition of the Bohai Rim multi-port system was in the "Efficiency Competition" area during this period. **¡Error! No se encuentra el origen de la referencia.** shows that in 1997, the container throughput of Qingdao Port surpassed that of Tianjin Port for the first time. Since then, Tianjin Port has been lagging behind Qingdao Port. The MVCs have gradually increased since 1997 to 0.5 in 2021, meaning that Qingdao Port has become the new leading port of the Bohai Rim multi-port system. Comparing the two figures, it was found that the MVC in the ternary graph is consistent with the CCI.

3.2 DPB analysis

¡Error! No se encuentra el origen de la referencia. shows that the values of NDPB were below 0.4 during the period 1981-2021 and the change in values is relatively stable. This indicates that the Bohai Rim multi-port system was equal and stable during this period. The NDPB fluctuated by 0.23 between 1981 and 1996, with a small fluctuation range. From 1997 to 2021, the NDPB rose slowly from 0.22 to 0.39. From 1981 to 2021, the overall values of NDPB showed an increasing trend, which means that the degree of decentralization of the Bohai Rim multi-port system was in a decreasing state, was stable in the initial stage, and gradually decreased in the latter.

The continuous decline in LI from 1980 to 2021 is presented in Figure 5. The LI fluctuated slightly around 0.36 and began to grow rapidly in 2019, reaching a peak of 0.43 in 2021. The closer LI tends toward zero, the closer the market share of all ports is (2006). It is preliminarily inferred that there are significant inequalities in container throughput in the multi-port system around Bohai Bay and that one certain port is gradually evolving into a northern shipping center. In Figure 5, we can observe the visual consistency between the DPB and LI curves. In this case, the correlation coefficient between NDPB and LI is 0.9948, indicating the validity of the verified hypothesis.

Fig. 5 Location of Bohai Rim multi-port system and map of gateway ports in Northeast Asia



3.3 CTC analysis

The above results have shown an evident evolution of the traffic composition in the Bohai Rim multi-port system. As exhibited in Section 3.1, although the change range of MVCs is small, the MVC of 1990 and 1997 in the Bohai Rim multi-port system were 0.46 and 0.43, respectively. The maximum market share was Tianjin Port and Qingdao Port in 1990 and 1997, which means that the leading ports of the Bohai Rim Port Group have changed. The years 1990 and 1997 can be regarded as two significant points in the ternary diagram (see **¡Error! No se encuentra el origen de la referencia.**). Therefore, the evolution of the Bohai Rim multi-port system is divided into three stages: from 1981 to 1990, from 1991 to 1996, and from 1997 to 2021.

¡Error! No se encuentra el origen de la referencia. shows the values of SSSA and CTC during the periods 1981–1990, 1991–1996, and 1997–2021. According to the results of CTC analysis, from 1981 to 1990, the market shares of Tianjin Port and Qingdao Port were -0.03 and -0.02 respectively, which were in a negative growth state, while the market shares of Dalian Port continued to grow positively and were 0.06. From 1991 to 1996, the shares of Dalian Port and Tianjin Port increased by -0.09 and -0.08, respectively, while the market share of Qingdao Port expanded by 0.17 during this period. From 1997 to 2021, the shares of Tianjin Port and Qingdao Port both grew positively, 0.04 and 0.07 respectively, while Dalian Port grew negatively. Obviously, Dalian Port was the biggest winner and Tianjin Port was the main loser from 1981 to 1990. After 1991, Qingdao Port was the main winner, while Dalian Port was the biggest loser.

As shown by SSSA, Dalian Port has lost the competitive advantage position that it enjoyed before 1990. Since 1991, it has been at the bottom of the competition with corresponding SSSA values of -0.0112 from 1991 to 1996, and -0.1475 from 1997 to 2021. On the contrary, Qingdao Port has strengthened its competitiveness and has been in the most competitive position since 1991, with 0.0002 and 0.0602 respectively. Tianjin Port has transitioned from its worst competitive state before 1990 to a strong competitive status after 1991, with -0.0086 and 0.0068.

CTC	1981-1990	1991–1996	1997–2021
Dalian Port	**0.06**	**-0.09**	**-0.11**
Tianjin Port	**-0.03**	-0.08	0.04
Qingdao Port	-0.02	**0.17**	**0.07**
Major winner	Dalian Port	Qingdao Port	Qingdao Port
Major loser	Tianjin Port	Dalian Port	Dalian Port
SSSA	1981-1990	1991–1996	1997–2021
Dalian Port	**0.7957**	**-0.0114**	**-0.1475**
Tianjin Port	**0.0188**	-0.0086	0.0068
Qingdao Port	0.0215	**0.0002**	**0.0602**
Major winner	Dalian Port	Qingdao Port	Qingdao Port
Major loser	Tianjin Port	Dalian Port	Dalian Port

Table 1 [Table caption explaining the components of the table]

4 DISCUSSION

To analyze the evolution of the Bohai Rim multi-port system, we calculated the values of MVC, DPB, and CTC of the Bohai Rim multi-port system during the period 1981-2020 and found that its concentration, inequality, and competition had changed significantly.

4.1 Period I: The dominant stage of Tianjin Port (1981-1990)

In Figure 4, the data points from 1981 to 1985 almost fell on the side of the "Efficiency Competition" area close to the leading area of Tianjin Port, and the values of MVCs and CCI were close to or equal to 0.5, which means that Tianjin Port was in the leading position of the Bohai Rim multi-port system during this period. The main reason for this is that the construction of the port is ahead of other ports in the Bohai Rim region. Tianjin Port is the first port engaged in container transport in mainland China (Wang, 2014). Tianjin Port began unloading international containers in 1973, and in 1981 a professional container terminal in Tianjin Port was completed and put into operation, the first dedicated special container terminal designed and constructed by the mainland of China. In 1984, Tianjin Port took the lead in implementing the port system reform, and construction of a container terminal began for the expressway. Since 1986, the MVCs have gradually decreased to 0.47 in 1990, indicating that the competitiveness of Tianjin Port has gradually decreased, while the competitiveness of Dalian Port and Qingdao Port has gradually increased. The reason for breaking the stranglehold of Tianjin Port is that Qingdao Port and Dalian Port started container operations in 1980. After a period of development, they gradually divided the market with Tianjin Port in the Bohai Rim region.

The overall fluctuation of the NDPBs and LI decreased slightly and the values were small, with the fluctuation range of NDPB between 1981and 1990 being 0.19 to 0.26, and the fluctuation range of LI being 0.36 to 0.38, indicating that the inequality of the Bohai Rim multi-port system was small during this period. On the whole, the development trend of the three ports was relatively equality the same.

In 1981-1990, the CTC of Tianjin Port, Dalian Port, and Qingdao Port were -0.03, 0.06, and -0.02 respectively. The container market shares of Tianjin Port and Qingdao Port showed negative growth, indicating that Dalian Port was the main winner in the competition of the Bohai Rim multi-port system during this period. The SSSA values including spatial factors are 0.07957, 0.0188, and 0.0215, showing growth. Considering that this period represented the rapid development stage of China's reform and opening-up, the economy in each region experienced explosive growth, resulting in positive SSSA values. Among them, the change in Dalian's GDP has the largest share in the value of SSSA, while Tianjin Port has the smallest share.

Overall, the inequality within the Bohai Rim multi-port system was minimal during the period indicated, with Tianjin Port holding dominance before 1986. Although the competitiveness of Dalian Port and Qingdao

Port has improved since 1986, Tianjin Port continues to maintain the largest share of the container market and the highest level of competitiveness.

4.2 Period II: The stage of efficiency competition (1991-1996)

As shown in Figure 4, the data points from 1991 to 1996 were in the "Efficiency Competition" area, and the MVCs declined rapidly from 0.47 in 1991 to 0.40 in 1996, along with the CCI value also decreasing from 0.48 to 0.4, indicating that the competition between the Bohai Rim multi-port system is intensifying. The three ports have all passed the construction period and have entered into a mature development phase, with competition entering a white-hot stage. The LI fluctuated slightly and always maintained at 0.36. The NDPBs were stable at around 0.2 and fluctuated slightly, meaning that the degree of decentralization of the Bohai Rim multi-port system was high and stable during this period. In 1991-1996, the CTC of Tianjin Port, Qingdao Port, and Dalian Port were -0.08, 0.17, and -0.09 respectively, with corresponding SSSA values of -0.0112, -0.0086, and 0.0002 respectively. The results show that Qingdao Port is the main winner in the competition of the Bohai Rim multi-port system and that Qingdao Port has become the most competitive port in the Bohai Rim multi-port system. Despite the rapid development of container transport in Qingdao Port, the overall development of Tianjin Port, Dalian Port, and Qingdao Port in this period is still relatively balanced, and the Bohai Rim multi-port system is in the situation of "Tripartite confrontation" of Tianjin Port, Dalian Port, and Qingdao Port.

During this period, Qingdao Port was in an advantageous position, which was closely related to its vigorous development. After 1991, the construction of Qingdao Port Container Terminal began, and Qingdao Port opened the first international container shipping route -- the direct trunk line of container transport to East America. In 1994, Qingdao had successively opened container routes to Japan and the West Coast of the United States. In 1995, the overseas container business operated by COSCO headquarters was relocated to Qingdao Port, making Qingdao Port the first international container transshipment port in mainland coastal ports (Chi, 1995). Qingdao Port has developed from a domestic container feeder port to an international container trunk port and an international container transshipment port. At the same time, Qingdao Port accelerated scientific and technological innovation and opened the Electronic Data Interchange (EDI) system for container transportation in 1996 to achieve the integration of container transportation information management with international standards.

Meanwhile, the construction of Dalian Port commenced more than a decade after Tianjin and Qingdao. Furthermore, although the economy maintained a stable development, the overall growth rate during this period was 3% lower than the national average, impeding the growth of foreign trade in Dalian Port and resulting in sluggish container throughput expansion (Dai and Zhang, 2001).

4.3 Period III: The rising stage of Qingdao Port (1997-2021)

In **¡Error! No se encuentra el origen de la referencia.**, the values of CCI and MVCs in the Bohai Rim multi-port system from 1997 to 2021 were in the "Efficiency Competition" area. The MVCs reached their maximum in 2020 and 2021, close to 0.5, and the same situation also occurs with CCI, which means that the Qingdao Port has experienced rapid container shipping development during this period., with the largest market share, and has occupied a leading position since 2020. The NDPBs were less than 0.5 from 1997 to 2021 (see **¡Error! No se encuentra el origen de la referencia.**) and remained stable at 0.2 from 1997 to 2010. The fluctuation began to increase in 2011 and began to increase after dropping to a minimum of 0.12 in 2013, until approaching 0.4 in 2021. Consequently, from 1997 to 2013, the LI fluctuated around 0.36, and reached its lowest point of 0.34 in 2013, followed by a slight increase to 0.37 in 2019, and a significant increase to 0.41 and 0.43 in 2020 and 2021, respectively. This means that the degree of decentralization of the Bohai Rim multi-port system is relatively high. Due to the growth of Qingdao Port, the concentration of the Bohai Rim multi-port system will reach the maximum in 2021. From 1997 to 2021, the market shares of Tianjin Port, Dalian Port, and Qingdao Port were 0.04, -0.11, and 0.07 in CTC and -0.1475, 0.0068, and 0.0602 in SSSA respectively, indicating that Qingdao Port was the most competitive port in the Bohai Rim multi-port system during this period and was the main winner, while Dalian Port was the biggest loser.

The container throughput of Tianjin Port has grown at an average annual growth rate of 13.7% since 1997, although the growth rate was slightly slower compared to 14% of Qingdao Port. The main reason is that the handling capacity of the container terminal is seriously insufficient. In this context, Tianjin Port has increased its investments in port construction. In 2010, Tianjin Port achieved a container throughput of 10.086 million TEU, exceeding the 10 million TEU mark for the first time, making it one of the largest container ports in the world. At the same time, the berth utilization rate reached 84.8%, which shows that the container terminal supply in Tianjin Port is basically consistent with the import and export demand. After 2010, the negative effects of the CNY 4 trillion stimulus package completely emerged (Feng et al., 2021). Tianjin's GDP growth rate from 2012 to 2015 was 11.3%, 10.1%, 7.5% and 6.9% respectively. The economic slowdown led to a decline in the import and export volumes. Correspondingly, the growth rate of container throughput at Tianjin Port decreased to 6.1%, 5.8%, 8.1%, and 0.4% respectively. The period of rapid development of Tianjin Port came to an end. In 2021, the container throughput of Tianjin Port will reach 20.27 million TEU. The average annual growth rate during this period was 5.8%, and the containers in Tianjin Port entered a period of moderate growth.

Since 1997, Qingdao Port has successively opened scheduled international express boutique routes with full refrigerated containers, exceeding 1 million TEU for the first time, with an annual growth rate of 28%. At the end of 2002, 18 new routes were added with the opening of the Huangdao Port Area of Qingdao Port. The economic hinterland of Qingdao Port continued to expand, and the number of containers increased rapidly. By the end of 2010, the container throughput of Qingdao Port had reached 12.01 million TEU. This period represents the period of rapid development Qingdao Port, with an average annual growth rate of 20.7%. In 2019, China (Shandong) Pilot Free Trade Zone Qingdao was launched, promoting the development of container transportation in Qingdao Port by simplifying the transport process and reducing costs (Jin Lianjie, 2022). The Pilot Free Trade Zone delivered rapid growth in 2020 and 2021, making Qingdao Port has now become the real shipping center of Northeast Asia. During this period, the average annual growth rate of Qingdao Port was 6.2%, and the containers in Qingdao Port have entered a stage of moderate growth.

Due to the Asian Financial Crisis, the GDP growth rate of Dalian dropped to 10.1% in 1997, which led to the container throughput of Dalian Port being 453,000 TEU, with an annual growth rate of 7.6%, a new historical low point. The government implements a series of measures to quickly restore the economy. With the commissioning of the new container berths in 1999 and 2000, the annual handling capacity of Dalian Port has a growth rate of 37.2%, exceeding the growth rate of 31.2% of Tianjin Port, and almost equal to the growth rate of 37.5% of Qingdao Port. In 2007, the Dayaowan Bonded Port Area of Dalian Port was officially put into operation. At the end of 2010, the container throughput of Dalian Port was 5.262 million TEU. This period represents the stage of rapid development of Dalian Port, with an average annual growth rate of 20.8%. Since 2011, the GDP growth of the three northeastern provinces of China has declined. In 2015, the GDP growth of Heilongjiang Province, Jilin Province, and Liaoning Province had dropped to 5.7%, 6.5%, and 3.0%, respectively, 6.5, 7.2 and 9.1 percentage points lower than that of 2011. As the direct hinterland of Dalian Port, the GDP growth rate fell to 5.5% and 4.1% in 2014 and 2015 respectively. The economic downturn led to a reduction in the import and export of container goods. In 2015, Dalian Port completed a container throughput of 9.583 million TEU, with a growth rate of - 1.4%, showing negative growth for the first time. At the same time, the rapid development of Yingkou Port also brings pressure to Dalian Port. Dalian Port and Yingkou Port have the same hinterland, but compared with Dalian Port, the distance from the northeast inland of China to Yingkou Port has been shortened by 190 kilometers, greatly reducing land logistics costs. By 2021, the container throughput of Dalian Port was only 3.67 million TEU, 18% and 15.5% of the container throughput of Tianjin Port and Qingdao Port respectively. During this period, the average annual growth rate of Dalian Port was -5.4%. As a result, the container traffic at Dalian Port has entered a period of negative growth.

5 CONCLUSIONS

Tianjin Port, Dalian Port, and Qingdao Port in the Bohai Rim multi-port system have been among the top ten ports in terms of national throughput for many years, with each port having its own advantages and disadvantages as well as fierce competition. This paper explores the concentration, inequality, and competition of the Bohai Rim multi-port system from 1981 to 2021, highlights the evolution of the Bohai Rim multi-port system, and recommendations for the establishment of the northern China shipping center.

The findings indicate a significant shift in the dominance of the Bohai Rim multi-port system from Tianjin Port to Qingdao Port. In addition, the concentration of the system development has remained low and the three ports have not been fully monopolized. Tianjin Port, Dalian Port, and Qingdao Port are competing fiercely for the position of the northern China shipping center. In particular, Dalian Port has experienced sluggish container shipping growth with declining throughput for several years, indicating weak competitiveness and a challenging domestic and international environment. In contrast, as the first port to introduce container transport in mainland China, Tianjin Port has experienced a period of slow development since it was overtaken by Qingdao Port in container throughput in 1997. At present, container transportation in Dalian Port is developing slowly, and even the container throughput has been declining for several years. The competitiveness is weak and the domestic and international situation faced by Dalian Port is serious, so the prospects are not optimistic. As the first port to open container transport in mainland China, Tianjin Port has been in a period of slow development stage since its container throughput was surpassed by Qingdao Port in 1997. Qingdao Port, as a rising port, has a full momentum of development and is at the peak of development.

After analyzing the concentration, inequality, and competition of the Bohai Rim multi-port system from the perspective of the ternary diagram compared with the other three traditional methods, we believe that the northern China shipping center should be located in Qingdao Port to achieve the full utilization of social resources and the integration of regional ports, so as to better drive the development of the Bohai Rim multi-port system and the role of stimulating the regional economy.

The ternary diagram method proposed in this study is obviously more suitable for multi-port systems with only three ports. It can also be applied to analyze similar three-port systems, but it is not suitable for analyzing ports with two ports, four ports, and other quantities of ports, and is highly sensitive to the number of variables. In future research, the author will explore more widely applicable analytical methods.

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