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RESEARCH ON PORT COMPETITIVENESS AND PORT AND CITY SYNERGY IN CHINA'S BOHAI RIM

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Abstract. *Compared with other general enterprises, port enterprises have the unique characteristics of fixed geographic location, special economic status and natural monopoly of trade varieties. The Bohai Rim region is a relatively active economic zone in Asia, so this article selects Qingdao Port, Tianjin Port and Dalian Port and the hinterland: Shandong, Tianjin and Liaoning Province as the research objects, and other large coastal ports in China as the reference objects. We used entropy weight TOPSIS port competitiveness evaluation model combined and the dynamic panel data model to avoid the single-angle, single-dimension and single-subject problems prevailing in the study of port and hinterland relations. On this basis, we calculate and standardize the port location quotient, radiation intensity and cooperation degree of the port and city of the eight coastal node areas of China to characterize port contribution and port-hinterland synergy. The empirical research results show that the competitiveness of the three Bohai Rim ports has increased year by year, and the coordination between ports and hinterland has also increased year by year. However, compared with other large coastal port cities in China, the absolute and relative development speeds of the Bohai Rim areas are all slow.*

Keywords: Bohai Rim ports, Competitiveness, Port radiation intensity, Port and city synergy

1. **Introduction and Research Route.** The hinterland economy is the foundation and backing for the survival and development of the port, and the foundation of supply and demand for the development of the port. As the gateway to the hinterland and the window for economic promotion, the port is the basic support for the spatial structure of the hinterland. As an international logistics center integrating technology, capital, logistics and information, modern ports have an important radiating and leading role in its hinterland. The coordinated development of the port and the hinterland has become one of the important issues in port management. At present, the basic consensus on the research of port-hinterland relationship is that the port and its hinterland do have a cooperative development relationship, but they basically start from a certain aspect of the port. Although it is possible to clearly observe the interaction mechanism between a certain aspect of the port's ability and the economic development of the hinterland, it is impossible to observe the relationship between the comprehensive development of the port and its hinterland. Therefore, it is necessary to conduct a comprehensive evaluation of the port, and then calculate the coordination relationship between the port and the hinterland.

At present, a basic consensus on the research on the relationship between the port and the hinterland is that the port and its hinterland do have a cooperative development relationship. However, the above studies basically start from a certain aspect of the port

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indicators, such as from the perspective of port hardware scale. A representative study is by Meng and Gao, who studied the coupling relationship between port and city and its influence mechanism, and believed that port scale and hinterland economic scale have a positive impact on improving the coordination degree of port and city coupling [1]. There are also studies from the perspective of logistics development. For example, Shi and Li studied the relationship between the development of the port hinterland from the perspective of physical, logistics and macroeconomics. It is believed that the sustainable development of Shenzhen Port is that its hinterland should be inland and foreland direction extension [2]. There are also studies based on more specific indicators. For example, Yang et al. used the VAR model to select the cargo throughput of Lianyungang Port, its hinterland GDP, and the number of employments as the research variables. It is believed that the role of seaports in the hinterland regional economic development has obvious stages [3]. Although the above researches can clearly observe the mutual influence mechanism of certain aspects of the port's capabilities and the economic development of the hinterland, it is impossible to observe the relationship between the comprehensive development of the port and its hinterland. This aspect of research is currently relatively rare.

Port evaluation involves many aspects, including ecological evaluation, social benefit evaluation, and competitiveness evaluation. Among them, the competitiveness evaluation pays more attention to the quantification and comparison of the comprehensive strength and development status of the port, which can objectively reflect the comprehensive development level of the port. At present, the evaluation of port competitiveness generally focuses on the hardware facilities of the port, such as geographical location, telecommunications system, inland transportation, port throughput, operation capacity, natural environmental services and other factors, such as Liu et al., Zhang and Yan, Chen and Zhang and other port competitiveness evaluation studies [4-6]. In view of our country's infrastructure capacity, many hardware facilities will reach the expected level within a short period of time. In other words, these hardware levels are variable in the short term. There is no long-term coupling with the hinterland's macroeconomics. For example, Zhang and Meng and Chen have shown that port competitiveness not only depends on the improvement of infrastructure, but also depends on the level of port soft power [7,8].

The existing research has the following shortcomings.

First, most of the literature is qualitative analysis, lacking necessary empirical analysis and empirical testing; second, the evaluation index results are greatly affected by the sample; third, there are few studies on the comprehensive competitiveness of ports. However, port development is also affected by economic soft power factors such as policy, efficiency, inter-departmental smoothness, and the scale and structure of hinterland demand. Therefore, when evaluating port competitiveness, this article considers both economic and hardware factors. The evaluation indicators include economic and trade aspects and take the hardware facilities into account. Therefore, this paper selects the TOPSIS evaluation model with entropy weight. Compared with other subjective evaluation methods, this method combines subjective and objective evaluation, which basically solves the problem of difficulty in determining the weights in subjective evaluation and the limitation of algorithm for objective evaluation, and can explain the key factors that affect port competitiveness.

Therefore, from the perspective of comprehensive port development, this paper studies the synergy mechanism of the overall development of the port and its hinterland regional economic development, and determines the key factors and influence mechanisms of the hinterland that affect the comprehensive development of the port. In this way, the hinterland economic variables that affect the overall development of the port are described more accurately, and the researches on the coordinated development of the port and city, the layout of the port industry, and the promotion of the integration of the port and city are further improved.

This article is developed according to the following structure: Section 2 shows the evaluation of the competitiveness of the three major ports; Section 3 describes the calculation of the degree of coordination between the comprehensive development of the port and the economic development of the hinterland; Section 4 presents the conclusion of the article.

2. Port Competitiveness Evaluation.

2.1. Establishment of indicator system. As mentioned above, this article considers both port hardware conditions and software strength when evaluating port competitiveness. Therefore, the index system of this article should meet the following requirements: first, the indicators can objectively reflect the comprehensive competitiveness of the port, including the hinterland's support for the port; second, the indicators are objective and comparable horizontally and vertically; third, the most representative key indicators should be selected, and indicators that will change rapidly in the short term should be ignored. Therefore, the indicators selected in this article are indicators reflecting port throughput capacity, indicators reflecting port operation capacity, indicators reflecting port hinterland support, and economic indicators reflecting port soft power. The above four types of indicators can be divided into the following specific indicators in detail.

Table 1. Evaluation index system of port competitiveness

Criterion layer	Index layer
Port throughput capacity	Port container throughput
	Port cargo throughput
	World ranking of cargo throughput
	World ranking of container throughput
Port operation capacity	Port production berth
	Maximum berth
	Berths over 10,000 tons
	Number of routes
Comprehensive capability of port hinterland support	Land area
	Enterprise total assets
	Number of navigable ports
Port trade soft power	Number of imported products
	Number of export categories
	Total import
	Total exports

2.2. Establishment of evaluation model. Determine the normalization matrix. Taking port throughput capacity as an example, there are 4 indicators representing the throughput capacity of each port, namely, port container throughput, port cargo throughput, cargo throughput world ranking, and container throughput world ranking. The 4 indicators are expressed as: X_1, X_2, X_3, X_4, $X_i = \{x_1, x_2, \ldots, x_n\}$.

$$Y_{ij} = [x_{ij} - \min(x_i)]/[\max(x_i) - \min(x_i)] \tag{1}$$

In Formula (1), Y_{ij} represents the normalized value of the corresponding position in the normalized matrix. On this basis, use the formula

$$P_{ij} = Y_{ij} \Bigg/ \sum_{j=1}^{n} Y_{ij} \tag{2}$$

Normalize the index to get the normalized matrix. Here P_{ij} is the corresponding position element of the normalized matrix N. Then find the information entropy of each index.

According to the definition of information entropy in information theory, there are

$$E_i = -\ln(n)^{-1} \sum_{j=1}^{n} P_{ij} \ln P_{ij} \tag{3}$$

Use Formula (3) to find the information entropy of the corresponding index. After calculating the corresponding index information entropy E_i, finally determine the weight of each index, using the following formula:

$$W_i = (1 - E_i) \Big/ \left(k - \sum E_i\right) \quad (i = 1, 2, \ldots, k) \tag{4}$$

Equation (4) can calculate the weight W_i of the corresponding index, which is introduced into the TOPSIS algorithm as the weight of the weighting matrix.

2.3. **TOPSIS algorithm.** First determine the normalization matrix, this step has been determined in the entropy method, so we will not repeat it. The second step is to construct a weighted normalized matrix Z, whose elements Z_{ij} are

$$Z_{ij} = W_i N \quad (i = 1, 2, \ldots, k;\ j = 1, 2, \ldots, n) \tag{5}$$

where W_i is the weight of the index, and N is the normalized matrix. The third step is to determine the ideal solution and the negative ideal solution, that is:

$$\begin{aligned} Z^+ &= \left(Z_1^+, Z_2^+, \ldots, Z_n^+\right) = \left\{\max_i Z_{ij} \,|j = 1, 2, \ldots, n\right\} \\ Z^- &= \left(Z_1^-, Z_2^-, \ldots, Z_n^-\right) = \left\{\min_i Z_{ij} \,|j = 1, 2, \ldots, n\right\} \end{aligned} \tag{6}$$

Among them, Z^+ is the ideal solution set, and Z^- is the negative ideal solution set. The fourth step is to use

$$\begin{aligned} D_i^+ &= \sqrt{\sum_{j=1}^{n} \left(Z_{ij} - Z_j^+\right)^2} \quad (j = 1, 2, \ldots, n) \\ D_i^- &= \sqrt{\sum_{j=1}^{n} \left(Z_{ij} - Z_j^-\right)^2} \quad (j = 1, 2, \ldots, n) \end{aligned} \tag{7}$$

Find the distance from a feasible solution to a positive and negative ideal solution for any index. Finally, use Formula (8)

$$C_i = D_i^- \big/ \left(D_i^- + D_i^+\right) \quad (i = 1, 2, \ldots, k) \tag{8}$$

Finally, the relative closeness C_i between the feasible solution and the ideal solution of a certain index is calculated, and then the evaluation objects are sorted according to the relative closeness. The larger C_i indicates the stronger the competitiveness of the corresponding evaluation object.

2.4. **Competitiveness evaluation of the second layer indicators.** Using the above Formulas (1) to (8), we can obtain the relative closeness. Then use the four relative closeness of criterion layer as the second layer indicator, and Formulas (1) to (8) are repeatedly used to find the comprehensive competitiveness of each port. The source of the data in this article is the China Economic Net statistical database, CNKI statistical database, 2000-2020 Qingdao, Tianjin, Dalian, Shandong Province, Liaoning Province local statistical yearbook, Qingdao, Tianjin, Dalian Customs, China Port Net, etc. Formulas (1) to (8) are used to calculate the relative proximity indicators and competitiveness rankings

Table 2. Relative closeness (rc) of ports in 2020

Index / Ports	Throughput		Operation capacity		Capability of port hinterland support		Soft power	
	Ranks	rc	Ranks	rc	Ranks	rc	Ranks	rc
Qingdao Port	1	0.4988	2	0.2662	2	0.2886	1	0.3854
Tianjin Port	2	0.4838	1	0.3102	1	0.8424	3	0.0585
Dalian Port	3	0.3178	3	0.1971	3	0.2629	2	0.2769

Table 3. Evaluation results of comprehensive competitiveness of various ports over the years

Index / Years	Relative closeness		
	Qingdao Port	Tianjin Port	Dalian Port
2000	0.1722	0.2634	0.2278
2001	0.1796	0.2747	0.2286
2002	0.1769	0.2762	0.2257
2003	0.1929	0.3046	0.2242
2004	0.1953	0.3095	0.2215
2005	0.1960	0.3130	0.2191
2006	0.1965	0.3155	0.2183
2007	0.2037	0.3271	0.2222
2008	0.2061	0.3260	0.2217
2009	0.2088	0.3334	0.2252
2010	0.2159	0.3458	0.2232
2011	0.2108	0.3354	0.2221
2012	0.2007	0.3213	0.2232
2013	0.1893	0.3040	0.2233
2014	0.2252	0.3713	0.2150
2015	0.2359	0.3929	0.2110
2016	0.3207	0.4132	0.2081
2017	0.3396	0.4102	0.2153
2018	0.3501	0.4235	0.2360
2019	0.3529	0.4456	0.1960
2020	0.3601	0.4538	0.1997

of the standard-level port throughput capacity, port operation capacity, port hinterland support comprehensive capacity and port economic soft power. Due to the large amount of data, this article only shows the 2020 results. See Table 2.

The relative proximity of the above four criterion levels is used as the second-level index, and the results obtained by Formulas (1) to (8) are repeatedly used. The results are shown in Table 3.

3. **Port-Hinterland Synergy.** Compared with the port's own hardware indicators, the port's contribution to the development of the hinterland can more intuitively and accurately reflect the synergistic relationship between the port and the city. Therefore, when analyzing the port-hinterland synergy, this paper introduces port throughput capacity, operation capacity, hinterland support comprehensive capacity, trade soft power, and port competitiveness indicators into the port subsystem as a sequence parameter reflecting the port's contribution to the hinterland, and introduces urbanization into the port subsystem. Rate is introduced into the city subsystem as the order parameter. Then, the coordination degree model of the composite system is used to calculate the degree

of coordination between the port and the city composite system. The composite system coordination degree model is currently widely used in port-city collaboration research. It provides a measurement criterion for the implementation of composite systems based on the collaborative management effect, which can comprehensively consider the operating conditions of the port subsystem and the city subsystem. First calculate the order degree of the order parameter component system of the subsystem:

$$X_{ij} = \begin{cases} (x_{ij} - \beta_{ij}) \,/\, (\alpha_{ij} - \beta_{ij}) \,, \; x_{ij} & \text{Positive utility} \\ (\alpha_{ij} - x_{ij}) \,/\, (\alpha_{ij} - \beta_{ij}) \,, \; x_{ij} & \text{Negative utility} \end{cases} \tag{9}$$

According to the synergy theory, the larger the value of X_{ij} in Formula (9), the greater the contribution of the sequence parameter component x_{ij} to the order of the system. α_{ij} and β_{ij} are the maximum and minimum values in the order parameter matrix, respectively. Then use

$$V(x_i) = \sum_{j=1}^{n} \omega_{ji} X_{ij}, \quad \sum_{j=1}^{n} \omega_{ji} = 1 \tag{10}$$

Equation (10) is used to obtain the total contribution of the sequence parameter component to each subsystem. In Equation (10), ω_{ji} is the weight of each sequence parameter component. Since the number of sequence parameter components in the system in this paper is small, the correlation matrix is used to assign weight method to determine the indicator weight. Finally, suppose that the orders of the port subsystem and the city subsystem at the initial time of the system are V_1^0 and V_2^0. After a period of evolution, the orders of the system become V_1^t and V_2^t. Then the degree of synergy of the composite system can be defined as:

$$S_{it} = \theta \sqrt{|V_1^t - V_1^0| \times |V_2^t - V_2^0|}, \quad \begin{cases} 1, & V_1^t - V_1^0 > 0 \text{ and } V_2^t - V_2^0 > 0 \\ -1, & \text{or} \end{cases} \tag{11}$$

According to Formula (8), Formula (9) and Formula (10), the degree of coordination between ports and hinterland over the years can be calculated, and the results are shown in Table 4.

Table 4 shows the port-hinterland synergy index of the 8 coastal areas from 2000 to 2020, which can also be called the port-city synergy. Comparing the changes in the degree of coordination between ports and cities in various regions, we can find that there are irregular changes in various regions, which exposes the rapid economic development in our country since 2000, the large changes in industrial layout, and the uneven development of various industries. Observing the changes in the degree of coordination between port and city since 2014, it is found that the degree of coordination between port and city in other regions except Liaoning Province has increased, but they are all weak.

4. **Conclusions.** The calculation results of the article show that whether it is the average competitiveness or the average growth rate of competitiveness, Dalian Port ranks last among the three major ports in the Bohai Rim. From the perspective of competitiveness, it is still a port with a higher level of economic development in the hinterland that has strong comprehensive competitiveness.

However, there is indeed a certain gap between the economic development level of the hinterland regions of ports with relatively weak competitiveness and the stronger ports.

First, the added value of the secondary and tertiary industries and fiscal budget revenue in the hinterland have a significant boost to port competitiveness, indicating that the economic structure has a significant role in enhancing port competitiveness.

Second, the port's own competitiveness has a certain inertia, indicating that there is a certain degree of Matthew effect among our country's major ports, and it is more difficult for ports with weak competitiveness to surpass those with strong competitiveness. The

Table 4. The degree of coordination between ports and hinterland in coastal areas from 2000 to 2020

Years	Fujian	Shandong	Shanghai	Hainan	Zhejiang	Liaoning	Guangdong	Tianjin
2000	0.0216	0.0074	0.0200	0.0174	0.0627	0.0029	0.0191	0.0097
2001	0.0216	0.0074	0.0200	0.0174	0.0627	0.0029	0.0191	0.0097
2002	0.0395	0.0186	0.0215	0.0124	0.0089	0.0202	0.0278	0.0142
2003	0.0351	0.0199	0.0218	0.0142	0.0232	0.0214	0.0434	0.0330
2004	0.0402	0.0007	0.0197	0.0358	0.0411	0.0348	0.0685	0.0056
2005	0.0672	0.0744	0.1743	0.0315	0.0458	0.1229	0.0541	0.0315
2006	0.0520	0.0323	0.0360	0.0245	0.0134	0.0224	0.0208	0.0182
2007	0.0387	0.0247	0.0343	0.0573	0.0142	0.0164	0.0228	0.0424
2008	0.0212	0.1445	0.3276	0.0237	0.0239	0.0169	0.0869	0.1436
2009	0.0260	0.1121	0.1172	0.0358	0.0099	0.0016	0.0453	0.2209
2010	0.1232	0.2625	0.0542	0.0030	0.0304	0.1043	0.1887	0.0557
2011	0.0165	0.1217	0.0717	0.0158	0.0833	0.0620	0.1465	0.0193
2012	0.0353	0.0489	0.0009	0.0027	0.0410	0.0573	0.0476	0.0245
2013	0.0160	0.0384	0.0090	0.0384	0.0149	0.0366	0.0218	0.0142
2014	0.0301	0.0397	0.0004	0.0447	0.0255	0.0812	0.0374	0.0144
2015	0.0301	0.0366	0.0402	0.0215	0.0466	0.0255	0.0314	0.0097
2016	0.0727	0.0674	0.0078	0.0481	0.0860	0.0058	0.0618	0.0300
2017	0.1377	0.1601	0.1307	0.1601	0.1366	0.1583	0.1435	0.1359
2018	0.0459	0.0555	0.0162	0.0605	0.0413	0.0970	0.0532	0.0302
2019	0.0336	0.0401	0.0437	0.0250	0.0501	0.0290	0.0349	0.0132
2020	0.0743	0.0690	0.0094	0.0497	0.0876	0.0074	0.0634	0.0316

economic growth rate of the hinterland is not an effective guarantee for the competitiveness of the port.

Third, the regional trade and logistics situation in the hinterland has a significant role in promoting port competitiveness.

Fourth, the enhancement of port competitiveness and the development of logistics in its hinterland have a significant role in promoting the development of the regional secondary and tertiary industries, indicating that the enhancement of port competitiveness helps to rationalize the adjustment of the regional economic structure.

Based on the competitiveness evaluation of this paper and the conclusions of the panel model, this paper believes that there is a mutual promotion and mutual influence relationship between our country's ports and their hinterland areas. The hinterland's role in promoting the port is mainly reflected in the rationality of the hinterland's economic structure and the development of hinterland regional trade and logistics. The influence of the port on the hinterland economy is mainly realized by boosting the secondary and tertiary industries. The enhancement of the port's own competitiveness requires consideration of both software and hardware. The prerequisite for improving the competitiveness of ports is to adjust the economic structure of the hinterland, in order to increase the scale and speed of the flow of factors in the region, and to provide the port with product demand and impetus.

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