Dynamic measurements and mechanisms of coastal port–city relationships based on the DCI model: Empirical evidence from China

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\section*{A R T I C L E   I N F O}

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- DCI model
- Impulse responses
- China

\section*{A B S T R A C T}

The port–city relationship is not only one of the major contradictions in the development of port cities but also an important factor that affects the sustainable development of coastal areas. Therefore, determining the port–city relationship and identifying the mode of port–city interaction are difficult yet popular topics in research on port cities. The argument is based on a reciprocal port–city relationship. This study uses the main coastal port cities in China as research objects to propose the dynamic centralisation index (DCI) of port–city relationship based on the relative concentration index and to verify its effectiveness. In accordance with the measurement and classification of port–city relationships between 2001 and 2015, we discuss the influences of port sizes and internal structural changes on the port–city relationship. In addition, we use the impulse response function to explore the mechanisms of different types of port–city relationships. The primary objectives of this study are as follows: (1) to propose a new measurement model of port–city relationship that fully reflects the relationships of port sizes and structural changes to urban development; (2) to use the DCI model to classify port–city relationships, explore the change characteristics of different types of port–city relationships and further verify the validity, sensitivity and applicability scope of the DCI model; and (3) to determine the manifestation of port–city interaction and identify its dominant factors in different port cities. The strength or tendency of port–city relationships is not directly related to port or city size but is closely associated with underlying issues, such as the development stage of port or city and the relationship between port and hinterland.

\section*{1. Introduction}

Port cities comprise a special city type, exhibiting the dual attributes of ports and cities. (Wang & Liu, 2000). They are not only nodes of transportation systems but are also centres of regional social and economic activities (Hoyle, 1997). As hub nodes of international logistical supply chains, ports play an increasingly important role in supporting urban and regional economic development with expanding globalisation (Ponzini, 2011). Most economically developed regions and cities in the world are integrated with ports, such as London, Hamburg, Rotterdam, and Marseilles in Europe; Los Angeles, New York and San Francisco in North America and Yokohama, Kobe, Busan, Singapore, Hong Kong, Shanghai and Shenzhen in Asia. These places are not only important ports but are also core cities and critical hubs for the global economy. In developing countries, particularly foreign trade-oriented countries, such as China, port cities serve as open ports and regional gateways in facilitating economic globalisation.

On the one hand, the continuous development of the modern port economy and port cities requires that ports and cities coexist in a limited space within which their interaction is constantly strengthened. The port–city relationship has become an important factor that affects the development of ports, cities, and coastal areas; it is of considerable significance to the development of ports and their hinterlands. On the other hand, a port is the core advantage of a port city. The port–city relationship is the key factor that influences a port city’s sustainable development; it is one of the major contradictions throughout the entire process of the development of port cities. Therefore, systematic research on the port–city relationship must be strengthened in the context of global economic integration, particularly with regard to new factors and characteristics of this relationship in the era of globalisation and the global supply chain. Such study is crucial for understanding the development pattern and achieving the sustainable development of port cities.

Port cities are considered the space carrier and economic centre of the port economy. There cities have becomes the centre of the circulation of resources, funds, information and talents because of their

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special location, traffic conditions and capability to optimise resource allocation (Yang, Zhang, et al., 1986; Zhao & Lv, 2005). With the expanding development of globalisation, the coastal ports of developing countries are becoming increasingly important carriers of international industrial transfer. In this context, the number of coastal ports in China is increasing, the scale of the port system is expanding and a port city system with a similar urban system is gradually forming. The China Port Yearbook and the China Traffic Statistics Yearbook from 2001 to 2015 reported that the number of coastal ports above the scale in Mainland China increased from 8 to 27 in 2001–2015, the cargo throughput of the ports increased from 1.5 billion tons to 12.8 billion tons and the container throughput increased from 27 million to 199.6 million standard boxes. The volume and container throughput are nine and seven times, respectively, of the values 15 years prior. With an increase in port number and changes in port size distribution, the optimisation of the port cargo structure has been remarkable. The level of port modernisation represented by container transportation has been considerably improved, and the coastal zone of Mainland China has developed from a coastal city zone to a port city zone (Fig. 1).

China has a large number of different types of port cities, with > 50 coastal port cities alone. These cities, including Tianjin, Ningbo, Quanzhou, Xiamen, Guangzhou, and Yantai, have a long history of development and have become regional gateways and hub ports in the process of opening up commercial ports in modern times. These cities have a history of > 100 years, during which they have risen rapidly to become modern regional hub ports, with prominent port cities, such as Shanghai, Dalian, Qingdao, Qinhuangdao, Shenzhen, and Lianyungang. In addition, since the beginning of this century, new ports, such as Tangshan, Gangzhou, Rizhao, Suzhou, and Wenzhou, have emerged since the beginning of this century as a result of hinterland economic development. The port development history, development stages and functions of these cities are different, and their levels of urban development and industrial structure also vary. A major deviation was observed in the past when the relative concentration index (RCI) model was used to analyse the relationship between ports and cities in these cities. In several emerging port cities, the growth of port transportation fluctuated considerably, and the static RCI value was frequently too high or too low to reflect the impact of ports on urban development. Therefore, a new model based on RCI should be developed to accurately determine the relationship amongst different port cities.

Accordingly, the current study draws on the basic concept of RCI to propose a new dynamic centralisation index (DCI) model based on index updating and factor analysis, namely, dynamic RCI. The innovations and theoretical contributions of this study are reflected in three aspects. Firstly, RCI theory has been widely applied since its introduction and has become an essential method for quantitatively characterising the port-city relationship. However, with the advancement of shipping technology, the optimisation of port transport systems, and the emergence of multifunctional port development, the original index can no longer comprehensively reflect a port's current development status. The use of population to reflect city size is also restricted by various factors, such as human migration and negative population growth. Therefore, one of the important innovative contributions of this study is to upgrade multiple aspects of the original RCI model to demonstrate the fundamental characteristics of the port–city relationship in a comprehensive and concise manner.

The second aspect of this work concerns the dynamics by which the development of a port city diversifies when a port becomes multifunctional. What is the role of the port–city relationship in the development of a port city? What are the common traits of the port–city relationship for cities at different levels and stages of development? For a large developing country such as China, does port growth depend more on its urban area or the wider hinterland regions? The answers to these questions involve several theoretical difficulties in functional mechanisms and growth dynamics of the port–city relationship and are also connected with scientific measurements and quantitative identification concerning the relationship. This study explored this aspect and achieved remarkable results.

The third aspect concerns the fact that China has many port cities and complicated port–city systems. The differences amongst various port cities are significant, given the existence of global hub port cities and emerging local port cities, which have different port functional
evolution and uneven transport structures and service levels. Under these conditions, whether effective quantitative indicators can be used to measure the port–city relationship of different cities and examine the basic characteristics and regional differences of port–city relations in developing countries in this era of globalisation is not only of substantial theoretical value but also of beneficial practical application.

This case study is based on data derived from China’s major coastal port cities and focuses on three related issues. Firstly, it summarises the research progress and problems concerning comparative studies on the port–city relationship in China and in the west. It also highlights the shortcomings of the quantitative analysis of the port–city relationship. Secondly, this research proposes a new DCI model based RCI and the new characteristics of port city development. It presents a new DCI model and uses this model to classify and analyse the evolution of the port–city relationship in coastal cities. Thirdly, this work adopts the impulse response function to systematically analyse the factors that drive different types of port–city relationships. It explores the mechanisms of different types of port–city relationships and provides an understanding of the driving degree of each factor.

2. Research review and research framework

Geographic research on the port–city relationship began in the 1930s with port location theory (Yang et al., 1986), under which five major research areas were formed. The first area focuses on the spatial characteristics, patterns and evolution stages of the relationship between the locations of ports and cities. On the basis of empirical cases of port cities from various countries or regions, scholars have proposed multiple port systems and port spatial development models, such as the Anyport model and the Taaffe six-stage and four-stage models (Bird, 1963; Taaffe, Morrill, & Gould, 1963; Rimmer, 1967; Notteboom & Rodrigue, 2005; Liang, Cao & Wu, 2011; Wu & Gao, 1989; Guo, Du & Han, 2015; Rizzo, 2014; Dehrie & Raimbault, 2016). The second area concentrates on the industrial development of port areas and its impact on the region. From the perspectives of port industry, port logistics, and waterfront living space, scholars have examined the impacts of industrial development in ports and adjoining areas on regional industrial functions, environments, recreational spaces and redevelopment (Hoyle, 1989; Vigarie, 1981; Butt, Xie, Costa, et al., 1994; Akhavan, 2017; Ye, Cao, & Wang, 2018; Shen, Liu & Zhang, 2010; Bruttomesso, 1993; Tang, Chan, & Griffiths, 2015). The third area involves the connection between port and city networks. Many scholars (e.g. Wang & Hong, 2016; Guo, Wang, Wang, et al., 2017) regarded containers and their shipping networks as the main entry point of port geography research. The fourth area addresses the sustainable development of interaction between ports and cities and the construction of green ecological ports. From the perspective of port and port city development, achieving a win–win situation between ports and cities enhances their capacities for sustainable development (Brooke, 1990; Gao, Chang, & Ye, 2010). The fifth area quantitatively measures the port–city relationship and explores the differences, connections and correlations of such relationship in various cities from a regional perspective. This type of research is represented by Vallega (1979), which selects relevant port and city indicators and obtains the ratio between them to reflect the types of port–city relationship after certain data standardisation. Vallega found that the port–city relationship varies considerably in different regions of the world. For example, most European port cities emphasise the role of ports in the entire continent, focusing on the development of transport and logistics industries; the interdependence index between ports and cities is relatively weak and stable. Meanwhile, Asian port cities primarily rely on coastal areas and the rapid development of port-related industries; thus, these port cities are highly interdependent and constantly declining (Wang & Ducruet, 2012). In general, the first two research areas have produced valuable outcomes in the past 80 years since the introduction of port location theory. By contrast, only a few studies are available on the quantitative analysis of the port–city relationship. There studies are either limited to RCI analysis or cannot reach an agreement because of the complexity and differentiation of the indicator system.

In particular, quantitative research on port–city relations has formed three major research fields. The first field proposes, amends and applies the RCI model. Many scholars have used RCI to categorise port cities (Ducruet & Jeong, 2005; Chen, Luan, & Wang, 2009; Jiang, Wang, & Liu, 2011) and further analyse the variation characteristics of the port–city relationship (Wu, 2012). The second research field discloses the multifaceted characteristics of the port–city relationship by constructing a relatively complex indicator system and applying a diversified quantitative model. The primary objective is to apply the grey correlation degree (Jiang, Gao, & Wu, 2007), the port–urban system dynamics model and system entropy (Yang & Pan, 2011) to investigate changes in the strengths of the port–city relationship and the state of system coupling. The third field proposes to construct a development theory of port cities and to explain their development stages on the basis of the quantitative characteristics or changes in the strengths of the port–city connection. Examples of research in this area include those of Wu & Gao (1989) who presented the growth model of port cities; Wang (2010), who created the port–city four model; Guo and Han (2013), who presented the port urban spatial system evolution model and Karel et al. (2018), who developed the port–city interface connection method.

In summary, existing quantitative methods for investigating the port–city relationship exhibit advantages and disadvantages. Firstly, the grey correlation degree can be used to determine the strength of port–city connection, but the results have poor interpretability. Secondly, coordination degree and system entropy rely on complex indicator systems to measure the statuses of port–city system fusion, which can theoretically deepen the internal association mechanism of a port–city system to a certain extent. However, many calculation processes and related intermediate variables exist, and the economic indexes of port systems are difficult to separate and acquire. The three aforementioned factors enhance the difficulty of normalising and promoting calculation standards. Thirdly, RCI is a simple and direct method for determining the relative strength of the association between ports and cities. However, the results are only relative due to differences between regions, and classification is highly subjective. In addition, the original indicators of port and city throughput and population cannot adapt to the new characteristics and conditions of port shipping and urban development.

Therefore, this study proposes the DCI model in accordance with the theoretical basis and research background of different models and the development stage of modern coastal port cities. The influences of different port sizes and internal structures on the port–city relationship are discussed on the basis of measuring and classifying its changing trend. In addition, the mechanism of different types of port–city relationship is discussed using the impulse response function to verify the validity, applicability, and sensitivity of the model. The theoretical framework is illustrated in Fig. 2.

3. Materials and methods

3.1. DCI model

3.1.1. RCI model

RCI was proposed by Vallega, 1979 to analyse the organisational relationship between ports and their associated residential areas in the Mediterranean region. RCI is defined as the ratio of the percentage throughput of a port in an entire region to the percentage population associated with the port, as expressed by the following formula:
The Evolution of Port–City Relations under the Background of Port Function Change and Sustainable Urban Growth

Spatial characteristics, patterns and evolution stages

The impact of port industry on region

quantitative research

Port level and Port network

Sustainable development of Ports and Cities

To propose, amend, and apply the RCI model

Applying diversified quantitative model

Starting from quantitative characteristics and strength change

Proposal of the DCI model

Growth rate: Elasticity Coefficient

Renewal of port and city indicators

Growth scale: relative concentration index

Empirical test

Classification of the port–city relationship

Port-driven city

Urban-driven city

Port–Urban interaction

Port function and power source of urban growth

VAR analysis

Theory promotion and plication Suggestions on

Growth rate: Elasticity Coefficient

\[
RCI = \left( \frac{T_i}{\sum_{j=1}^{n} T_j} \right) \left( \frac{P_i}{\sum_{j=1}^{n} P_j} \right)
\]

where \(T_i\) is the port cargo throughput of city \(i\), \(P_i\) is the total population of city \(i\), and \(n\) is the number of port cities within a certain region. The RCI value primarily represents the relative scale of ports and cities in a certain region, where \(RCI = 1\) indicates that port size is commensurate with city scale, \(RCI \to 0\) indicates that the role of the city in the port–city system tends to be important and \(RCI \to \infty\) indicates that the role of the port in the port–city system tends to be important.

3.1.2. Proposal of the DCI model

RCI has been used in relevant studies, all of which adopt Vallega's original calculation method of using the ratio of a port's percentage throughput to a city's total population to reflect the size of port and city functions. This index exhibits the advantages of simplicity in content, ease of obtaining data and convenient operation, but has three major shortcomings. Firstly, a large sample of urban resident population data is unsuitable for acquisition due to the adjustment of household registration and administrative divisions. Population alone is insufficient to reflect the overall scale and development level of a city. One reason for this condition is that the household registration policy of China makes the demographic statistics different from the urban permanent population. In particular, the proportion of nonhousehold registration population in cities increases with an increase in 'floating population' nationwide and permanent population data for long time series and large sample cities are unavailable. Another prominent reason why population alone is an insufficient factor for explaining city scale and development involves the acceleration of urbanisation. The adjustment of urban and rural administrative divisions becomes increasingly frequent along with the acceleration of urbanisation. These factors are already leading to drastic changes in the statistics of the urban population. By contrast, gross domestic product (GDP) statistics are common and can intuitively reflect the development of the urban economy.

The second shortcoming of RCI lies in the difference in port group classification between various regions when a regional port group is considered a whole. This limitation results in a relative accuracy of the measured port–city relationship, which renders such results unusable for inter-region comparison. The third shortcoming of RCI is related to the fact that such analysis selects only port cargo throughput at the level of a port's economic development when container transportation has become the mainstream of shipping worldwide. Given these facts, the volume and size of container transportation are better indicators of the modernisation level of ports. China's coastal container throughput has grown rapidly since the beginning of the 21st century. The coastal areas of China have established the world's largest, most active and
fastest-growing port shipping system and the largest container port system unit in the world.

Accordingly, this study uses port cargo throughput and container throughput as indicators of port development and uses GDP as an indicator of city development. On the basis of RCI and these three aforementioned values, this study proposes a DCI (dynamic concentration index) calculation model, namely, dynamic RCI, which is defined as the importance of the relative growth of a port’s transportation to the economic growth of a city with in a certain research period and study region.

The DCI standard values are reflected in terms of growth rate and growth scale to reflect the growth vitality and dynamic mechanism of ports, respectively, relative to their cities. The classification of DCI for the port-city relationship combines the advantages of RCI and considers the growth rate and growth scale of a port city to accurately determine its relative activity. The elasticity coefficient of port development emphasises the growth rate of a port relative to city development, and the RCI of port growth emphasises the proportion of a port relative to city growth. The theoretical basis is as follows. Firstly, the growth rate and scale emphasise the dynamic development of the port-city relationship from a dynamic perspective (Hall & Jacobs, 2012).

The elasticity coefficient of port city development is referred to as $D_c$ (for short). This coefficient, which refers to the ratio of the average growth rate of port transportation to the average growth rate of city economic development in a certain research period, is calculated using the following formula:

$$D_c = \left( \frac{T_n - T_0}{N - 1} \right) \left( \frac{C_n - C_0}{N - 1} \right)$$

where $T_n$ is the port throughput in the $n$-th year during the study period, and $C_n$ is the city GDP in the $n$-th year.

The relative concentration index of port city growth is referred to as $DCI$ ($D_c$ for short). This index, which refers to the ratio of the proportion of a port’s transportation growth in an entire region to the proportion of the city’s economic growth in that region during a certain research period, is calculated using the following formula:

$$DCI = \frac{0.5D_c + 0.5D_{ci}}{0.5D_c + 0.5D_{ci}}$$

where $D_c$ is the DCI value for port cargo throughput, $D_{ci}$ is the elasticity coefficient for port cargo throughput, $D_{ci}$ is the DCI for port cargo throughput; $DCI$ is the DCI value for port container throughput, $D_{ci}$ is the elasticity coefficient for port container throughput and $D_{ci}$ is the DCI for port container throughput.

The core idea of the DCI model is to calibrate the relative activity of port growth and urban development from the perspective of development and dynamics to measure the port–city relationship of a port city at a specific stage. On this basis, the weight of $D_c$ is determined to be 0.5 and that of $D_{ci}$ is 0.5. This research has a long time series because the proportion of container transportation in the entire port shipping is constantly changing. Therefore, this study assumes that port cargo throughput and container throughput are equally important in characterising the size and development level of a port. The average of their calculation results is used to indicate the DCI standard value. With respect to DCI classification, we refer to the general definition of the world’s seaport cities by Ducruet and Lee (2006), which is based on RCI, and the definition of port and city scales by Jiang et al. (2011) to generate a port–city relationship map (see Fig. 3).

### 3.2. 4Vector autoregressive (VAR)-based impulse response analysis

The VAR model was proposed by Fan et al. (2014). This model is typically used to characterise the dynamic effects of correlation and random perturbation terms of time series systems on variable systems. It exhibits the advantage of obtaining cross-regional information or patterns from regional economic event sequences (Du & Guo, 2014). The mathematical representation of the VAR model is

$$y_t = Bx_t + A_1y_{t-1} + A_2y_{t-2} + \ldots + A_py_{t-p} + \varepsilon_t$$

where $y_t$ is a $k$-dimensional endogenous variable vector; $x_t$ is a $d$-dimensional exogenous variable vector; $t = 1, 2, \ldots, T$ is the number of samples; $P$ is the lag order; $A_1, A_2, \ldots, A_p$ and $B$ comprise a coefficient matrix and $\varepsilon_t$ is a $k$-dimensional perturbation vector. Eviews 8.0 software is used to conduct an impulse response analysis of the interaction development mode between ports and cities on the basis of the aforementioned model (Guo, Du, Han, et al., 2015).

Stationarity and cointegration tests are the basis for impulse response and are adopted in this study as elaborated below. Firstly, the stationarity of each time series datum used in this study is verified using the Augmented Dickey–Fuller (ADF) test and the Phillips–Perron (PP) test. The results indicate that all variables are stable at the 5% level. Secondly, the cointegration test is performed to identify any long-term equilibriums and short-term fluctuations between time series.

### 3.3. Data source and processing

For a systematic and comprehensive study, this work combines the actual development statuses of port cargo throughput and container throughput and selects China’s 27 major coastal port cities of a certain scale (i.e. port cargo throughput exceeding 100 million tons or container throughput exceeding 1 million TEUs between 2001 and 2015) as research objects. Given the considerable variations in port city data within a narrow time window, this study uses the time window between 2001 and 2015 as the research period to reflect the overall development of port cities whilst minimising the impact of occasional data changes in certain years and making the data objective. The key steps in the calculation are as follows. The values of DCI, DCI, and DCI of each coastal city in the past 15 years are calculated using Formulas (2), (3) and (4), respectively.

4. Results

4.1. Classification of the port–city relationship

4.1.1. Classification of the port–city relationship based on the DCI model

The DCI values of China’s 27 coastal port cities are provided in Table 1. The DCI model can more reasonably represent and compare the relative development scales between ports and port cities than the RCI model, and thus better port city classification is produced. Therefore, the port–city relationship of China’s coastal port cities is divided into three types. The results of this study show that Yingkou has the largest DCI value (3.264), whereas Zhongshan has the smallest (0.634). The cities with DCI values significantly larger than 1.25 (in decreasing order of values) are Yingkou, Dandong, Rizhao, Tangshan, Lianyungang, Qinhuangdao, Xiamen, Ningbo, Zhanjiang and Jiangmen. These cities account for 37% of the 27 main Chinese coastal port cities. Their port–city relationship is characterised by the strong pull effect of the ports. These city features port in superior locations with vast hinterlands and exhibit certain degree of dependence on their ports; thus, they may be called port-driven cities. Yingkou, which ranks first with a DCI value of 3.264, is a new large-scale port that obtains extensive hinterland economic support due to its superior location under the promotion of the first round of China’s Northeast Revitalization Strategy (inaugurated in 2003 to reinvigorate the formerly strong northeastern industrial base, which has been lagging behind the eastern coastal areas since the 1990s), and its port development is considerably faster than the city development. Followed by cities with DCI values between 0.75 and 1.25, including Haikou, Qingdao, Yantai, Dalian, Shantou, Zuhai, Shanghai, Guangzhou, Quanzhou, Tianjin and Fuzhou. This type of city accounts for 41% of the 27 main Chinese coastal port cities. In such cities, the relative development between ports and cities tends to reach an equilibrium and exhibits positive port–city interaction; thus these port cities can be called port–city interaction cities. A third type of city represents those with DCI values < 1.25. Together, the eight cities account for 89% of all coastal port cities in China.

4.1.2. Measurement comparison of different indicators based on the DCI model

The DCI and DCJ values of the coastal cities are compared to further verify the validity of the DCI model. This comparison shows that 14 of the 27 major Chinese coastal port cities have undergone changes in port–city relationship, as measured using DCI, and DCJ. The DCI values of Zhanjiang and Jiangmen are 1.912 and 1.908, respectively, indicating that these cities are port-driven cities; however, their DCJ values are 0.820 and 1.074, respectively, indicating that there cities are port–city interaction cities. Zhongshan, Zhenjiang and Nantong are port–city interaction cities according to their DCI values, but their DCJ values suggest that they are urbanisation-driven cities. These observations indicate that these ports are small in development scale and are in the stages of scale expansion, hinterland capture, and transportation structure optimisation. These observations also indicate that these ports should rely on their own location advantages to enter the rapid growth stage. The DCI values of Ningbo and Qingdao are 1.053 and 0.972, respectively, and their DCJ values are 2.029 and 1.283, respectively. The DCJ values of Dongguan, Nanjing and Shenzhen are all smaller than their DCJ values. Each of these cities is city-driven on the basis of their DCI values but a port–city interaction city on the basis of their DCJ values. These observations show that the ports of these cities have undergone remarkable structural optimisation in their sources of goods, and the port modernisation level, which is represented by container transportation, has been considerably improved. The port–city relationship has undergone gradual changes, whilst the port transportation structure has promoted the development of the port–city relationship to a certain extent. With the rapid growth of container throughput, these ports have an increasing number of sources of goods suitable for container transportation, the transportation structure is becoming increasingly reasonable and the capability of these ports for sustainable development continues to be improved. (See Table 2.)

Combined with Fig. 4, the development characteristics of the port cities in three major regions, namely, the Bohai Sea, the Yangtze River Delta and the Pearl River Delta, are obtained. Firstly, amongst the nine cities in the Bohai Sea region, five cities (Yingkou, Dandong, Rizhao, Tangshan, and Qinhuangdao) belong to the port-driven city type, and three cities (Yantai, Qingdao, and Dalian) belong to the port–city interaction city type (closer to the port-driven city type, with 1 < DCI < 1.25). Together, the eight cities account for 89% of all cities in the Bohai Sea region. This finding indicates that the port...
development in the Bohai Sea region is relatively active and plays a significant promotional role in city development. The Di and De values of five cities in the region (Yingkou, Dandong, Rizhao, Tangshan, and Qinhuangdao) are > 1.25, and these cities accounting for 56% of all the cities in the Bohai Sea region. Therefore, the relative scale and growth rate of the ports of these cities are faster than those of the cities themselves, and the ports are driving the overall development of the related cities at the present stage. Five cities (Yingkou, Dandong, Rizhao, Qinhuangdao, and Yantai) have DCI values greater than their DCIt values, whilst four cities (Tangshan, Qingdao, Dalian, and Tianjin) have DCI values smaller than their DCIt values. The DCIt and DCIj values for each of these nine cities are above 0.724, indicating that the ports in the Bohai Sea region are in a stage of rapid development with the structural optimization of sources of goods.

### Table 2
Calculating results of different indicators of port cities in coastal areas of China.

<table>
<thead>
<tr>
<th>Cities</th>
<th>DCIj value and Rank</th>
<th>DCIt value and Rank</th>
<th>Cities</th>
<th>DCIj value and Rank</th>
<th>DCIt value and Rank</th>
<th>Cities</th>
<th>DCIj value and Rank</th>
<th>DCIt value and Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yingkou</td>
<td>3.285(1)</td>
<td>2.673(1)</td>
<td>Yantai</td>
<td>1.239(10)</td>
<td>1.283(13)</td>
<td>Quanzhou</td>
<td>0.838(19)</td>
<td>0.890(17)</td>
</tr>
<tr>
<td>Dandong</td>
<td>3.234(2)</td>
<td>2.631(3)</td>
<td>Zhubai</td>
<td>1.193(11)</td>
<td>1.225(24)</td>
<td>Fuzhou</td>
<td>0.813(20)</td>
<td>0.861(23)</td>
</tr>
<tr>
<td>Rizhao</td>
<td>3.037(3)</td>
<td>2.302(5)</td>
<td>Haikou</td>
<td>1.154(12)</td>
<td>1.211(9)</td>
<td>Dalian</td>
<td>0.767(21)</td>
<td>0.844(12)</td>
</tr>
<tr>
<td>Tangshan</td>
<td>2.366(4)</td>
<td>2.156(2)</td>
<td>Ningbo</td>
<td>1.053(13)</td>
<td>1.165(6)</td>
<td>Tianjin</td>
<td>0.724(22)</td>
<td>0.820(21)</td>
</tr>
<tr>
<td>Zhanjiang</td>
<td>1.986(5)</td>
<td>2.150(22)</td>
<td>Zhongshan</td>
<td>0.987(14)</td>
<td>1.164(27)</td>
<td>Guangzhou</td>
<td>0.730(23)</td>
<td>0.811(15)</td>
</tr>
<tr>
<td>Qinhuangdao</td>
<td>1.912(6)</td>
<td>2.029(8)</td>
<td>Qingdao</td>
<td>0.972(15)</td>
<td>1.078(10)</td>
<td>Shanghai</td>
<td>0.689(24)</td>
<td>0.740(11)</td>
</tr>
<tr>
<td>Jiangmen</td>
<td>1.908(7)</td>
<td>1.689(16)</td>
<td>Zhenjiang</td>
<td>0.928(16)</td>
<td>1.074(25)</td>
<td>Dongguan</td>
<td>0.671(25)</td>
<td>0.569(18)</td>
</tr>
<tr>
<td>Liaoyungang</td>
<td>1.633(8)</td>
<td>1.660(4)</td>
<td>Nantong</td>
<td>0.901(17)</td>
<td>0.925(26)</td>
<td>Nanjing</td>
<td>0.570(26)</td>
<td>0.451(20)</td>
</tr>
<tr>
<td>Xiamen</td>
<td>1.459(9)</td>
<td>1.288(7)</td>
<td>Shantou</td>
<td>0.891(18)</td>
<td>0.890(14)</td>
<td>Shenzhen</td>
<td>0.417(27)</td>
<td>0.360(19)</td>
</tr>
</tbody>
</table>

![Fig. 4. Comparison of the results of DCIt and DCIj, De and Ds in different cities.](image1)

![Fig. 5. Law of the DCI evolution port cities in coastal areas of China.](image2)
Amongst the five cities in the Yangtze River Delta region, three cities (Nanjing, Zhenjiang, and Nantong) belong to the urbanisation-driven city type, and one city (Shanghai) is a port–city interaction city (closer to the urban-driven city type with, $1 < \text{DCI} < 1.25$). The four cities account for 80% of all the cities in the Yangtze River Delta region. This finding indicates that city development in the Yangtze River Delta is active, and the city’s pulling effect on the port is remarkable. The $D_c$ values of five cities (Shanghai, Nanjing, Zhenjiang, Nantong, and Ningbo) are between 0.75 and 1.25, and the $D_c$ values are $< 0.75$. This result indicates that the growth scale of these cities is faster than that of

![Graph showing port impact on cities.](image-url)
the ports, but the growth rate is approximately the same as that of the ports. Three cities (Shanghai, Nanjing, and Ningbo) have DCIj values less than their DCIi values, indicating that the ports in the Yangtze River Delta region are at a high level of development.

Amongst the six cities in the Pearl River Delta region, five cities (Guangzhou, Shenzhen, Dongguan, Zhongshan, and Zhuhai) have DCI values 0.75 and 1.25, accounting for 83% of all the cities in the Pearl River Delta region. This result indicates that the cities in this area are inclined towards interactive development. The Di and De values of five cities (Guangzhou, Shenzhen, Dongguan, Zhongshan, and Zhuhai) fluctuate around 0.75–1.25. These cities account for 83% of all the cities in the region, indicating that the growth rate and scale of the ports and cities in the Pearl River Delta region tend to be balanced. Three cities (Guangzhou, Shenzhen, and Dongguan) have DCI values less than their DCIj values, but the three other cities (Zhongshan, Zhuhai, and Jiangmen) have DCI values greater than their DCIj values. All the values fluctuate near 1, indicating reasonable port scale and cargo structure in the Pearl River Delta region.

Lastly, in terms of regional distribution, the cities in the Bohai Sea region, Yangtze River Delta and Pearl River Delta are mostly port-driven, city-driven and port–city interaction cities, respectively. These findings show that the growth of ports in the Bohai Rim region is more advanced than that of the cities, the growth of cities in the Yangtze River Delta region is more advanced than that of the ports and the interaction between ports and cities in the Pearl River Delta region is noticeable. The regional characteristics of the port–city relationship are remarkable and primarily determined by the hinterland economy and by the present stages of urban development and overall regional development.

We draw comparisons between the DCI-based classification results of the port–city relationship on the basis of existing research (Chen et al., 2009) and obtain the following findings. Firstly, the variation in DCI values may be due to an increase in port development rates or a decrease in city development rates. In addition, the DCI values emphasise growth vitality whilst being unrelated to the development scale of port cities when used for city type classification. For example,
Yingkou, Dandong, Rizhao, and Tangshan are typical port-driven cities with an increase in sources of goods and an outstanding capacity for container transportation. Dalian, Qingdao, Shanghai, Guangzhou, Haikou, Yantai, and Fuzhou are classified as port–city interaction cities with remarkable development of port–city interaction. Dongguan, Zhenjiang, Nanjing and Shenzhen are urbanisation-driven cities with a prominent level of port modernisation, which is closely related to the basis of city development. Secondly, the DCI model combines the growth rates, growth scales, and research regions; therefore, it accurately reflects the development stage of each coastal city and the port–city correlation status, thereby allowing port–city classification to have remarkable regional features. For example, the cities in the Bohai Sea region, Yangtze River Delta and Pearl River Delta are mostly port-driven, city-driven and port–city interaction cities, respectively. Thirdly, compared with RCI, the DCI model is more valid, exhibits higher sensitivity, and has a more widely applicable scope. It more reasonably shows the relationship of port sizes and structural changes to city development, and this capability is conducive to in-depth studies of the differences in driving factors and modes of action. Fourthly, port cities in developing countries differ from those in developed countries in terms of spatial evolution, development process, city size, and external conditions. The existing Anyport model (Bird, 1963) regards British ports as its research object, whilst the DCI model considers the nature of developing countries and new factors of port city development in the new era of globalisation; thus, it enriches the measurement model of the port–city relationship. Lastly, although Mina Akhavan’s (2017) four-stage evolution model fills the gap between less-developed and developing countries, it lacks comparison between port cities. The DCI model classifies the development status of port cities by comparing the development of each port city. This process is conducive to gaining a good understanding of the relationship amongst a port city, its regional development level, and the hinterland economy.

### 4.2. Trend analysis of DCI

The DCI value, which is calculated from 15-year data, reflects the overall situation of the port–city relationship within a specific period, but the relationship between ports and cities is change and develop. In order to analyse the changing characteristics of DCI value in each city and to further explore further the relative importance of ports and cities in different development stages. The values of DCI in the three research cycles (i.e. 2001–2005, 2006–2010 and 2011–2015) can be divided into four categories by observing their changes (Fig. 4). The cities of Qingdao, Dalian, Dongguan, and Zhuhai have continuously rising DCI values. The growth rate of ports from 2001 to 2015 was accelerating and gradually surpassing that of cities. The cities of Shanghai, Tianjin, Guangzhou, Qinhuangdao, Shenzhen, Lianyungang, Quanzhou, Zhanjiang, Shanxi, and Zhenjiang have continuously declining DCI values. This finding shows that the growth rate of the ports has slowed down between 2001 and 2015 compared with the growth rate of the urban economy. Cities with rising DCI values include Yantai, Zhenjiang, Dandong, Xiamen, Tangshan, Yingkou, and Rizhao. The port–city relationship of these cities exhibits an upward trend. Thus, the overall port development speed is faster than that of the city, and the city itself is in the self-development stage during the entire development process. Cities with declining DCI values include Nantong, Shantou, Jiangmen, Haikou, Fuzhou, and Ningbo. The relationship between these cities presents a downward trend. This result shows that the development speed of overall urban is faster than the port’s. Moreover, this result indicates that the city’s activity is changing and leading to the fluctuation of the DCI value of the port–city relationship. (See Fig. 5.)

### 5. Analysis of the mechanisms of action

In this section, we discuss the factors that affect the different types of port–city relationships. The port–city relationship can be analysed on the basis of the DCI values and their variation trends as being dominated by different transportation structures and by the variation characteristics of such relationships. However, deep insights into the mechanisms of different types of port–city relationships cannot be obtained. Therefore, we selected fixed-assets investment (investment), total industrial output value (industry), total retail sales of consumer goods (trade), tertiary industrial output value (tertiary industry) and urban freight volume (logistics) as primary factors that influence the port–city relationship. We then used the VAR model to conduct impulse response analysis of the 27 major Chinese coastal port cities to determine their driving mechanisms. For cities with DCI values > 1, we investigated the impulse response curves of the cities affected by the different factors of ports (Fig. 6). For cities with DCI values < 1, we investigated the impulse response curves of ports affected by the different factors of cities (Fig. 7).

### 5.1. Analysis of the mechanisms of port impact on cities

As shown in Fig. 6, for the 14 main Chinese coastal port cities with DCI > 1, a considerable difference exists between the cities and the factors in terms of their response degree to port impact. The action characteristics of the specific driving factors are summarised in Table 3.

<table>
<thead>
<tr>
<th>Types</th>
<th>Cities</th>
<th>Major factor</th>
<th>Second factor</th>
<th>Characteristics of impulse response changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>The degree of response fluctuates obviously</td>
<td>Dalian</td>
<td>Industry</td>
<td>Logistics</td>
<td>Except trade and tertiary industry, the impulses of other factors show dramatic positive and negative fluctuations</td>
</tr>
<tr>
<td></td>
<td>Yantai</td>
<td>Trade</td>
<td>Logistics</td>
<td>Trade fluctuates more significantly than other factors</td>
</tr>
<tr>
<td></td>
<td>Haikou</td>
<td>Trade</td>
<td>Logistics</td>
<td>The impulses various of factors show dramatic positive and negative fluctuations</td>
</tr>
<tr>
<td></td>
<td>Xiamen</td>
<td>Trade</td>
<td>Logistics</td>
<td>Trade and tertiary industry fluctuate significantly</td>
</tr>
<tr>
<td></td>
<td>Tangshan</td>
<td>Industry</td>
<td>Logistics</td>
<td>Except trade and tertiary industry, the impulses of other factors show dramatic positive and negative fluctuations</td>
</tr>
<tr>
<td>The degree of response fluctuates slightly</td>
<td>Qingdao</td>
<td>Investment</td>
<td>Industry</td>
<td>All factors show a significant positive spillover effect with strong persistence</td>
</tr>
<tr>
<td></td>
<td>Jiangmen</td>
<td>Industry</td>
<td>Trade</td>
<td>Except logistics, All factors show a significant positive spillover effect with strong persistence</td>
</tr>
<tr>
<td></td>
<td>Zhanjiang</td>
<td>Logistics</td>
<td>Investment</td>
<td>The impulses various of factors show obvious positive and negative fluctuations</td>
</tr>
<tr>
<td></td>
<td>Ningbo</td>
<td>Tertiary industry</td>
<td>Investment</td>
<td>Trade show a significant positive spillover effect, whilst the impulses of other factors show dramatic positive and negative fluctuations</td>
</tr>
<tr>
<td></td>
<td>Qinhuangdao</td>
<td>Logistics</td>
<td>Tertiary industry</td>
<td>The impulses various of factors show obvious positive and negative fluctuations</td>
</tr>
<tr>
<td></td>
<td>Lianyungang</td>
<td>Logistics</td>
<td>Trade</td>
<td>The impulses various of factors show obvious positive and negative fluctuations</td>
</tr>
<tr>
<td></td>
<td>Rizhao</td>
<td>Logistics</td>
<td>Tertiary industry</td>
<td>The impulses various of factors show obvious positive and negative fluctuations</td>
</tr>
<tr>
<td></td>
<td>Dandong</td>
<td>Tertiary industry</td>
<td>Investment</td>
<td>The impulses various of factors show obvious positive and negative fluctuations</td>
</tr>
</tbody>
</table>

Table 3: Comparison of the mechanism of port impact on cities.
Table 4
Comparison of the mechanism of city impact on ports.

<table>
<thead>
<tr>
<th>Type of Response</th>
<th>Cities</th>
<th>Major Factor</th>
<th>Second Factor</th>
<th>Characteristics of Impulse Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluctuates</td>
<td>Zhongshan</td>
<td>Logistics, tertiary industry</td>
<td></td>
<td>The impulses of various factors show dramatic positive and negative fluctuations</td>
</tr>
<tr>
<td>Fluctuates</td>
<td>Nantong</td>
<td>Trade, tertiary industry</td>
<td></td>
<td>The impulses of various factors show dramatic positive and negative fluctuations</td>
</tr>
<tr>
<td>Fluctuates</td>
<td>Shenzhen</td>
<td>Investment, logistics</td>
<td></td>
<td>The impulses of various factors show intensive positive and negative fluctuations</td>
</tr>
<tr>
<td>Fluctuates</td>
<td>Nanjing</td>
<td>Logistics</td>
<td></td>
<td>The impulses of various factors show dramatic positive and negative fluctuations</td>
</tr>
<tr>
<td>Fluctuates</td>
<td>Zhenjiang</td>
<td>Trade, logistics</td>
<td></td>
<td>The impulses of various factors show dramatic positive and negative fluctuations</td>
</tr>
<tr>
<td>Fluctuates</td>
<td>Dongguan</td>
<td>Logistics</td>
<td></td>
<td>The impulses of various factors show dramatic positive and negative fluctuations</td>
</tr>
<tr>
<td>Fluctuates</td>
<td>Guangzhou, Zhuhai, Shantou</td>
<td>Trade, investment</td>
<td></td>
<td>The impulses of various factors show intensive positive and negative fluctuations</td>
</tr>
<tr>
<td>Fluctuates</td>
<td>Tianjin</td>
<td>Investment, logistics</td>
<td></td>
<td>The impulses of various factors show dramatic positive and negative fluctuations</td>
</tr>
<tr>
<td>Fluctuates</td>
<td>Quanzhou, Shanghai</td>
<td>Investment</td>
<td></td>
<td>The impulses of various factors show intensive positive and negative fluctuations</td>
</tr>
</tbody>
</table>

The cities with a remarkably fluctuating response to the impact of the different port factors are Dalian, Yantai, Haikou, Xiamen, Tangshan, and Yingkou, which account for 43% of the 14 main Chinese coastal port cities with DCI > 1. At least one factor in this type of city has an impulse response higher than ±10%. Cities with fewer fluctuations in impulse response are Qingdao, Jiangmen, Zhanjiang, Ningbo, Qinhuangdao, Lianyungang, Rizhao, and Dandong, which account for 57% of the 14 main coastal port cities with DCI > 1. The impulse response of each factor in this type of cities is within the range of −10% to 10%.

Amongst the 14 cities with DCI > 1, four cities have logistics and industry as the most important acting factors through which the ports drive the cities. Two cities have trade, investment and tertiary industry as the most important acting factors, and four cities have logistics and investment as the second most important acting factors. Three cities have trade as the most important acting factor, two have tertiary industry as the most important acting factor and one has industry as the most important acting factor. Overall, amongst the 14 cities with DCI > 1, those with logistics and industry as the most important acting factors through which the ports drive the cities have the highest proportions, with each accounting for 29% of the 14 main Chinese coastal port cities with DCI > 1. The cities with logistics and investment as the second most important acting factors account for the highest proportion, each accounting for 29% of the 14 main Chinese coastal port cities with DCI > 1.

The cities with significantly different responses to the impact of various port variables are Haikou, Jiangmen, Zhanjiang, Ningbo, Qinhuangdao, Lianyungang, Rizhao, Dandong, and Yingkou, which account for 36% of the 14 main coastal port cities with DCI > 1. In such type of cities, the impact of a port on each variable of the city is unique; that is, a single factor plays a leading role whilst other factors play minor roles. Cities with slight differences in response to the impact of various port variables are Dalian, Yantai, Haikou, Xiamen, Zhanjiang, Guangzhou, Zhuhai, Shantou, which account for 57% of the 14 main Chinese coastal port cities with DCI > 1; in such city type, the impact of a port on each variable of a city exhibits multiplicity; that is, multiple factors jointly promote a city’s economic development. By contrast, the economic development of port cities is diverse and depends on various distinct factors.

5.2. Analysis of the mechanisms of city impact on ports

As shown in Fig. 7, for the 13 main Chinese coastal port cities with DCI < 1, a considerable difference exists between the ports and factors in terms of their response degree to cities’ impact. The action characteristics of specific driving factors are summarised in Table 4.

The ports with evidently fluctuating responses to the impact of different city factors are Zhongshan, Nantong, Shenzhen, Nanjing, Zhanjiang, Dongguan, Guangzhou, Zhuhai, and Shantou, accounting for 69% of the 13 main Chinese coastal port cities with DCI < 1. At least one factor in this type of city has an impulse response higher than ±10%. Cities with fewer fluctuations in impulse response are Fuzhou, Tianjin, Quanzhou, and Shanghai, which account for 31% of the 13 main Chinese coastal port cities with DCI < 1. The impulse response of each factor in this type of city is within the range of −10% to 10%.

Amongst the 13 cities with DCI < 1, six cities have logistics as the most important acting factors through which the cities drive the ports. Three cities have trade as the most important acting factors, and there cities regard investment and industry as the most important acting factors. Four cities have logistics and tertiary industry as the second most important acting factors, two cities have industry and investment as the second most important acting factors and one city regards trade as the second most important acting factors. Overall, amongst the 13 cities with DCI < 1, those with logistics as the most important acting factors through which the cities drive the ports have the highest proportions, accounting for 46% of the 13 main Chinese coastal port cities with DCI < 1. Cities with logistics and tertiary industry as the second
most important acting factors account for the highest proportion, each accounting for 29% of the 13 main Chinese coastal port cities with DCI < 1.

The ports with significantly different responses to the impact of various city variables are Zhongshan, Shenzhen, Dongguan, Tianjin, Guangzhou, Shanghai, and Zhuhai, accounting for 54% of the 13 main Chinese coastal port cities with DCI < 1. In such port type, the impact of a city on each city variable exhibits uniqueness; that is, a single factor plays a leading role whilst other factors play minor roles. The ports with slightly different responses to the impact of various city variables are Nantong, Nanjing, Zhenjiang, Fuzhou, Quanzhou, and Shantou, which account for 46% of the 13 main Chinese coastal port cities with DCI < 1. In such city type, the impact of a port on each variable of a city exhibits multiplicity; that is, multiple factors jointly promote a city’s economic development.

6. Conclusion and discussion

6.1. Conclusion

This study proposes the DCI model, which is based on RCI, of the port–city relationship. Compared with the RCI model, the DCI model exhibits the following characteristics or advantages. Firstly, it considers the development of container- and throughput-focused port cities, and thus reasonably identifies the relationship of port sizes and structural changes to city development. Secondly, the port–city relationship in China’s main coastal port cities is divided into three types, namely, port-driven, the port–city interaction and the urbanisation-driven types. This feature accurately reflects the development stage of each coastal city and the port–city correlation status, providing the port–city classification with remarkable regional features. Most of the ports in the port-driven cities have a prominent container transportation capability, but a joint development has not yet been fully realised in these port cities. For the port–city interaction cities, the port–city relationship can be evaluated based on the basis of the current development level, but a few port cities still have a certain two-way development space for both port and city. Most of the city-driven cities have a prominent level of port modernisation, which is closely related to the foundational facilities of city development. In terms of regional distribution, the cities in the Bohai Sea region, Yangtze River Delta and Pearl River Delta are mostly port-driven, urbanisation-driven and port–city interaction cities, respectively.

The impulse response function is used to systematically analyze the driving factors of the different types of port–city relationships by focusing (particularly) on a Chinese test case to explore the driving mechanisms of different types of relationships in port cities (generally) throughout the world. The results show different influencing factors and action mechanisms of port–city interaction and the port development under various factors. For the 14 cities with DCI > 1, those with logistics and industry as the most important acting factors through which the ports drive the cities have the highest proportions, with each accounting for 29%. Cities with logistics and investment as the second most important acting factors account for the highest proportion, with each accounting for 29%. For the 13 cities with DCI < 1, those with logistics as the most important acting factors through which the cities drive the ports have the highest proportions, accounting for 46%. Cities with logistics and tertiary industry as the second most important acting factors account for the highest proportion, with each accounting for 29%. Overall, logistics is the primary means to promote the economic growth of port cities. In recent years, the modern logistics industry in Chinese coastal port cities has developed rapidly, and logistics has become a direct bond for the interaction between ports and cities. Ningbo, Shanghai, Suzhou, and Nanjing are typical cities from this type, in which a complete and complex industrial system centred on logistics has been formed to drive economic development to a large extent. The impulse responses of the cities with considerable differences in factor effects exhibit uniqueness, whilst the impulse responses of cities with slight differences in factor effects exhibit multiplicity.

6.2. Discussion

Port–city interaction is a critical factor for the formation, growth, evolution and sustainable development of port cities. Therefore, the development patterns of port cities should be recognized, and the current developmental status of the port–city relationship should be further clarified to provide a theoretical basis for the optimization and sustainable development of this relationship. This study integrates the DCI model with the impulse response analysis to determine the port–city relationship of the major coastal port cities in China and analyse the driving mechanisms. Consequently, the relationship between port development, particularly transport structure optimization, and city development, is explained. Firstly, in terms of constructing the port–city relationship quantitative model, compared with the RCI model, the DCI model redirects the previous focus on the total size of the port to the growth rate and growth scale of the port, and thus the driving mechanism of the port–city relationship is determined from a dynamic and regional comparison perspective. Various regions have different development processes and types of port cities, and the development of the port and the urban areas are at different growth stages and structural levels. Therefore, a model that determines the port–city relationship must consider broad types of such relationship and effectively define the volatile properties of this relationship.

Secondly, the influencing factors of the port–city relationship in coastal cities and the theoretical perspectives of the driving mechanism indicate that cities in the circum-Bohai-Sea region, Yangtze River Delta area and Pearl River Delta area are predominantly port-driven, urban-driven and port–urban interaction cities, respectively. These findings suggest that different cities in the same region frequently share the same port–city relationship, but the characteristics and types of these cities demonstrate regional characteristics. Thus, the relative active level of port and city development is more closely related to the development status of the hinterland than of the urban area. This result further demonstrates the conspicuous nature of regional gateways in the port city development, given that not only the port is developed from the needs of the hinterland; development in the urban area also requires strong support from the hinterland. This regional consistency in port–city relationships, the diversity in the development stages and types of port cities and the coexistence of significant differences amongst cities demonstrate the influential role of ports in regional development and international trade in this era of intensified globalization. Ports are not only centres of international logistics but also hubs of the globalised economy system. The activity degree and structural optimisation level of ports represents the activity degree of the growth of the regional economy and the structural level of regional trades to a certain extent.

Thirdly, the port–city relationship is developing dynamically. The development of the port should not remain in an understanding of the overall scale but should focus on the optimisation of port transport structure and the stability and sustainability of cargo source organization. In consideration of the shortcomings of the existing literature, the design concept of this dynamic quantitative model offers universality and practical application value for the rapid development of the port economy.

Informed by this study on practical application, we proposed four suggestions for coastal port cities. Firstly, regional hub port cities have a long history of development, a high level of urbanisation and relatively perfect modern port functions; thus, these cities exhibit the characteristics of faster urban development than that of ports. The port–city relationship should be optimised, and the renewal of waterfront areas should be strengthened. From the perspective of port–city integration and continuous optimisation, a city can achieve sustainable development whilst realising synchronous port development and
avoiding a lag of port’s function. Secondly, China’s emerging coastal port cities have remarkable location advantages and are close to the central cities in the hinterland, showing that port development is faster than city development. We should increase the speed of supporting services for port-related industries around the development of ports; develop good plans for port development, particularly for the integration of the port industry and improve the high added value and competitiveness of the port industry through the implementation of a diversification strategy. Thirdly, the level of integration of ports and cities should be improved on the basis of two aspects to develop interactive coastal port cities, namely, industrial and spatial integration. In terms of industry, industrial integration and high-end development should be formed through the integration of port vicinity manufacturing and service industries. Spatially, urban planning should be adopted to continuously accelerate the redevelopment of waterfront areas and the comprehensive utilisation of space. This process will convert port–city spatial conflict to spatial integration and provide support for the sustainable development of port–city relations. Fourthly, ports will remain as strategic resources of port cities in the foreseeable future. For all coastal port cities, the transfer of port resources and the vitality of port development should be enhanced on the basis of shipping centres, free trade zones and cross-border electronic trade of free trade ports to transform ports from being supply chain nodes to port hubs. Port cities should embrace globalisation and the new economy. Combining tangible logistics with invisible e-commerce can enhance the innovation ability and development vitality of ports, and consequently realise ports’ conversion from the third-generation logistics centres to fourth-generation resource hubs.

This study has several shortcomings. Firstly, this research adhered to simple and direct measurement principles in DCI modelling and did not fully incorporate complicated indicators due to the difficulty of obtaining large sample data. Secondly, in the VAR model-based analysis of the driving mechanism, which is subject to a statistical index, several indicators that expressed multifunctional port development were replaced with blue substitution values. Lastly, the effects of the impulse response process and the differences between two-way effects were not included in this study due to space limitations. These shortcomings will be overcome by in-depth research in the future.

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References


