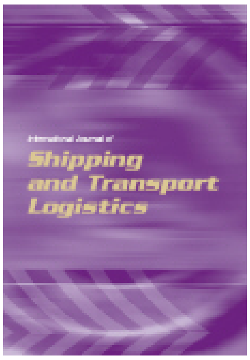

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Abstract: This study aims to explore the dynamic coupling relationships and the inter-lagging effects between the port and port city based on the auto-regression distribute lag model (ARDL) and error correction model (ECM). An empirical analysis of the Yangtze River Delta multi-port system was performed for illustration and verification purposes from the perspective of container traffic and the economy of the port city. Results show that port container traffic and the economy of the port city have significant interaction for both short- and long-run relationships, but different-scale ports have different port-city relationships and different inter-lagging effects. The findings also show that tertiary industry (TI) activities are the most associated with port development, secondary industry (SI) is second, and primary industry (PI) has less connection with port development. Meanwhile, with the extension of the lagging periods, the positive and negative effects are always declining. In terms of methodology, this framework is also helpful and applicable to other ports and port cities worldwide, and the empirical analysis also can provide managerial insight for policymakers and investors.

Keywords: port-city dynamic coupling relationships; inter-lagging effects; ARDL-ECM; the Yangtze River Delta multi-port system.

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1 Introduction

Ports as nodal infrastructures connecting global and local markets have played a key role in world trade (Feng et al., 2021a; Cullinane and Haralambides, 2021), and they are traditionally regarded as a strategic economic endowment that can promote the process of globalisation (Huang et al., 2022). Meanwhile, economic prosperity or disruptions can also promote or hinder the development of ports (Notteboom et al., 2021). Therefore, understanding port and economic linkages is critical for port governance and the growth of regional economies (Wan et al., 2014; Fedi et al., 2022).

A city that has a port with the functions of a water and land transportation hub is called a port city (Cong et al., 2020). The economy of the port city is one of the most important factors in port development, and port container traffic can also accelerate the development of the port city (Cheung and Yip, 2011; Cuevas et al., 2022). For instance, from the perspective of scale economics theory, services provided by ports positively impact industry productivity in different ways, and the main way including improving efficiency and reducing transport costs, which in turn can produce various effects, such as higher productivity of other inputs, growth of the trade and improvement of scale relevant market (Bottasso et al., 2014; Slack and Gouvernal, 2016). Meanwhile, port traffic has a significant effect on GDP, while it has an opposite impact on total retail sales of consumer goods. In terms of economic structure indicators, port traffic grows in parallel with secondary industry (SI), but is negatively correlated with primary industry (PI) and tertiary industry (TI) (Cong et al., 2020).

different ports have different impacts on the local economy, and different cities have different economic structures, which have different impacts on port development, but there is not enough evidence for this. On the other hand, there is relevant research to investigate the unidirectional effect of port activity on the regional economy or the regional economy on port activity (Cong et al., 2020; Li et al. 2023), but other literature rarely studied the bidirectional relationship between port activity and the regional economy.

Inter-lagging effects is a well-known term in economics, in which there is often an observed delay between an economic action and a consequence. Inter-lagging effects may exist between the time a problem is recognised and the time a policy has its impact on a system (Bian et al., 2021). Understanding the inter-lagging effects between ports and the port city can expedite decision-making. Consequently, in this paper, we analysed the long- and short-run bidirectional relationships and inter-lagging effects between the port and port city using ARDL and ECM.

ARDL bounds test proposed by Pesaran et al. (2001) was utilised for cointegration analysis. According to Nusair and Olson (2022), the ARDL and ECM are excellent approaches to exploring both long – and short-run relationships. The advantage of an ARDL is that this model can handle the variables at different lag orders, which cannot be met by other methods. Another benefit is that the ARDL bounds test does not need to have the same level of stationary to perform the analysis. At the same time, the ARDL-ECM is applied in many fields, such as environmental protection (Sufyanullah et al., 2022), and economics (Nusair and Olson, 2022). Therefore, ARDL and ECM are a good candidate to explore the long – and short-run dynamic relationships and inter-lagging effects between port and port city.

Compared with the current research about the port-city relationship, this contribution mainly proposed a useful and complete framework to explore the long- and short-run bidirectional relationships and the inter-lagging effect between port and city. Furthermore, a vector autoregressive (VAR) model is used to test the robustness of the results. The findings will show if the port container traffic and the economy of the port city have significant interaction and then can provide managerial insight and a better understanding of the port-city development pattern. In terms of methodology, this paper proposed a complete analytical framework to explore the dynamic coupling relationships and the inter-lagging effects between economic indicators of the port city and port container traffic. An empirical analysis of the Yangtze River Delta (YRD) multi-port system was performed for illustration and verification purposes, but the framework we proposed is also useful and applicable to other ports and port cities worldwide.

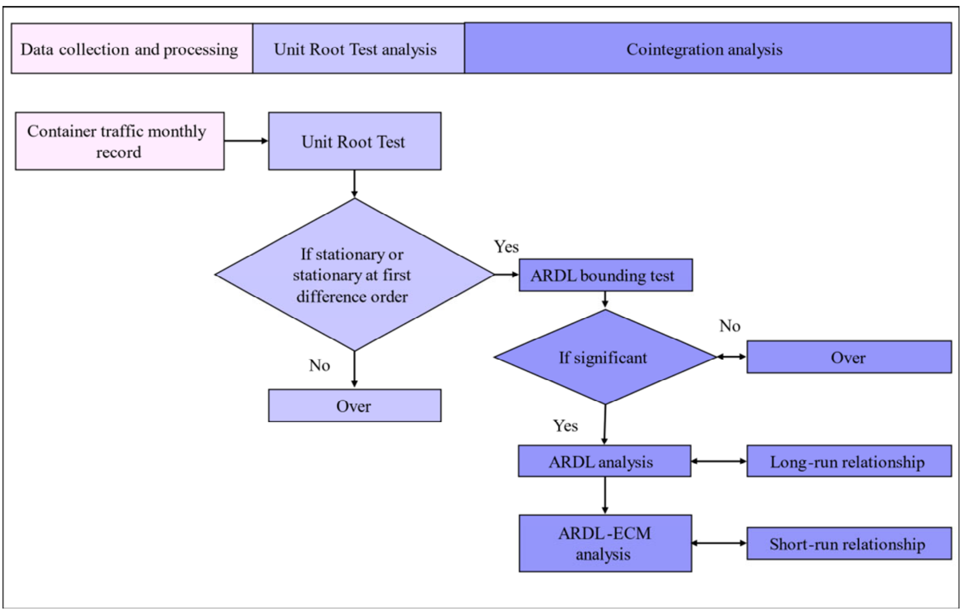
The remainder of this paper is organised as follows. Section 2 is the literature review. Section 3 introduced the analytical framework and methodology. Section 4 is the case study and Section 5 is the discussion. Finally, we got the conclusion in Section 6.

2 Literature review

Each port has its indispensable function that is closely related to the structure of the local economy, especially through its role in transportation. For example, Bottasso et al. (2014) applied a spatial panel econometric framework to analyse the impact of port activities on local development in European countries, they found that ports not only have important effects on local GDP but also take place outside the region where the port is located. Cong et al. (2020) used a panel data regression model to examine the relationships between economic indicators of the port city and the port traffic, they pointed out that port traffic has a positive effect on SI, but is negatively correlated with PI and TI. Park (2018) found that the economic effects of Busan Port on the manufacturing industries in Korea are positive, and the trans-shipment activity of Korean container ports does not affect overall the output of Korean manufacturing industries in the port cities and other regions. Grossmann (2008) pointed out that with the development of world technology and economy, the city should make changes according to the port development. Otherwise, the market shares would be lost by competitors. Significant infrastructure changes can influence the economic structure and port specialisation, thus affecting the distribution of economic activities (Ducruet et al., 2012; Fu et al., 2023).

Port is an advantageous condition for the development of the port city, and economic indicators such as employment and value-added have always been important factors in demonstrating the contribution of port development to local governments and community economies (Park, 2017; Grifoll et al., 2018). Xiu and Zhao (2021) found that the expansion of the port can improve port city development. Port cities are nodes of the world commodity flows, which could provide advanced services related to shipping and port activities (Jacobs et al., 2010). The shipping service industry depended on port development would bring employment to the port city. However, with the development of emerging technologies, such as deindustrialisation, containerisation and the adoption of automated port handling systems and technologies, the employment created per ton of cargo has been declining. Moreover, with increasing mechanisation of the ports, direct employment decreased (Bryan et al., 2006). This is also indicated by the evidence from Belgian Port (Dooms et al., 2015). While the value added per ton or TEU is increasing with the development of new handling technologies. This leads to a shift of logistics activities to the port hinterland, which in turn increases employment in the hinterland and reduces the value added per ton or TEU and employment in the port city (Notteboom and Rodrigue, 2005).

Figure 1 The analysis process of this paper (see online version for colours)



An insightful discussion of the relationship between port production and local economic development helps to enrich the understanding of port-economy interaction (Crotti and Ferrari, 2022; Zhao et al., 2023). A large amount of literature echoes that ports are the catalysts for the economic development of a region, accelerating economic industry integration and service agglomeration, thereby generating socioeconomic benefits (Funke and Yu, 2011; Song and Geenhuizen, 2014; Zhao et al., 2017). According to Ma et al. (2021), port integration has a positive effect on the economic growth of cities in the YRD, particularly in small- and medium-sized port cities. Heijman et al. (2017) inferred that world trade has been contributed by ports because the shipping industry plays a foundational role in global import and export trade from the case of the Rotterdam Port. Vanoutrive (2010) analysed the Antwerp Port case and found that the lagging effect is different in different regions. According to Merk et al. (2011), the Rouen Port contributed more than 21% of GDP in 2007. Meanwhile, improved accessibility and decreased transportation costs for a port help to boost the market potential (Condeço-Melhorado et al., 2011). Akhavan (2017) applied the four-phase model as the tool to explore the interface of port fixed assets investment and port throughput, the findings reveal that the creek dredging and newly constructed ports integrated with infrastructures have played an important role in boosting the economic growth in Dubai.

The mentioned contributions have inspired the development of a complete framework to explore the dynamic relationships between port and port city, which can facilitate the development of both port and port city. Meanwhile, understanding the inter-lagging effects between port and port city can provide permanent perspectives for policymakers and investors. Particularly we considered the port container traffic of the nine ports and three major industries of nine port cities in the YRD multi-port system.

3 Methodology

The analysis process of this paper is shown in Figure 1. The first step is the unit root test. Unit root test is used to identify the stationary of the variables before employing the ARDL to avoid spurious regression and Unit Root Test is also necessary for the ARDL Bounds approach. In this paper, the Augmented Dickey-Fuller (ADF) test (Cheung and Lai, 1995), and the Phillips-Perron (PP) test (Cheung and Lai, 1997) are applied. When the unit root test finished, we executed the ARDL bounds test to identify whether there is a cointegration relationship among variables. Finally, ARDL and ARDL-ECM are used to explore the long- and short-run relationships and lagging effects.

In the real world, most of the time series does not have a cointegration relationship, so, the examination of the following hypothesis is performed utilising ARDL bound test based on F-statistics to detect whether cointegration:

H0 There is a cointegration relationship between variables.

H1 There is no cointegration relationship between variables.

The null hypothesis of no cointegration will be rejected when the upper limit of the critical value lies below the assessed F-statistic value and vice versa. Once the hypothesis is accepted, cointegration is existing.

ARDL bounds test proposed by Pearan et al. (2001) was utilised for cointegration analysis. According to Nusair and Olson (2022), the ARDL bounds test is an excellent approach to exploring both long- and short-run relationships between various time series. The advantage of an ARDL is that this model can handle the variables that have different lag orders, which cannot be met by other methods. Another benefit of the ARDL method is that the ARDL bounds test does not need to have the same level stationary (I(0)) or I(1) to perform the analysis, which is also other models cannot be met. Consequently, we can directly use the container traffic data for JX, ZJ, and TZZ in their levels, while other variables are utilised in their first differences. However, the drawback of the ARDL methodology is that none of the variables must be of I (2) or higher order.

ARDL is used for regression analysis between a dependent variable and several independent variables. In contrast to other statistical models, the variables required by ARDL should be played by their past values (autoregression) and the current and previous values of other variables (distribution lags). When there are two independent variables, an ARDL model of order p, k and q is defined as ARDL(p, k, q), which consists of p and k lags of independent variables and q lags of dependent variable, and the optional lags were selected by Akaike information criterion (AIC). The ARDL model is written as follows.

$$Y_t = \alpha + \sum_{i=0}^{p} \gamma_i X_{t-i} + \sum_{i=0}^{k} \beta_i Z_{t-i} + \sum_{i=1}^{q} \mu_i Y_{t-i} + \varepsilon_t. \quad (1)$$

In equation (1), α is constant, X_{t-i} and Z_{t-i} are independent variables, Y_t is the dependent variable, i is the lag order of each variable and ε_t is a random error term, γ_i and μ_i are short-run dynamic coefficients.

ARDL bounds test helps in identifying underlying variables regarded as a long-run relationship equation. If the underlying equation is identified, the ARDL model of the cointegrating vector is reparametrised into the ARDL-ECM. The ARDL-ECM results reveal short-run dynamic relationships between the variables.

We reparametrised equation (1) as follows:

$$\Delta Y_t = \alpha_0 + \gamma_0 ECM_{t-1} + \sum_{i=1}^{q} \beta_i \Delta Y_{t-i} + \sum_{i=0}^{p} \theta_i \Delta X_{t-i} + \sum_{i=0}^{k} \varphi_i \Delta Z_{t-i} + \mu_t. \quad (2)$$

In equation (2), α_0 is constant, Δ which means the first difference between the variables, ECM_{t-1} is the error correction term, γ_0 is error correction coefficient.

The ECM_{t-1} is defined

$$ECM_{t-1} = Y_{t-1} - \sum_{i=1}^{h} \frac{\beta_i}{\beta_0} X_{i,t-1}. \quad (3)$$

Based on equation (3), then the ARDL bounds test is applied.

$$H_0 : \beta_0 = \beta_1 = \beta_2 \ldots = \beta_H = 0$$

If H_0 is rejected, then we consider cointegration between variables.

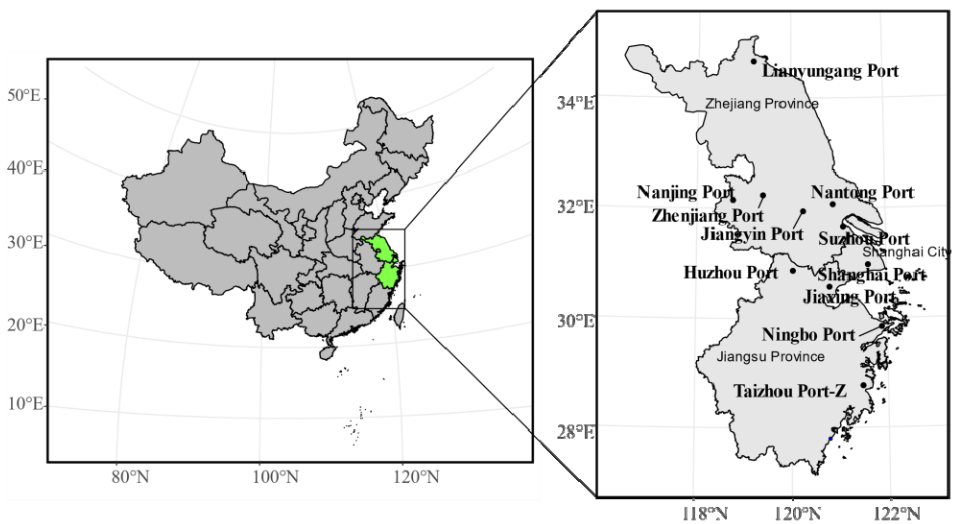
4 Case study

In the past few decades, China has developed into one of the world's largest economies. In this section, the proposed method is used to study the dynamic coupling relationship between the port and its city in the YRD region. In Section 4.1, we describe the statistical data used in this paper. Section 4.2 shows the Unite Root test results then ARDL and ARDL-ECM results are shown in Section 4.3, and finally, the robustness analysis is in Section 4.4.

4.1 Data description

According to Cong et al. (2020), port traffic is the most representative indicator for port development, at the same time, GDP is also the most important measurement of the development of the city, so in this paper, we selected the three major industries and port traffic as our research objection to conduct the study. PI involves the production of raw materials and has traditionally been the backbone of the economy of many port cities and SI involves the processing of raw materials and the manufacturing of goods. TI is closely related to the service industry, transportation, and finance. In this paper, the port container traffic in the YRD multi-port system and their cities' three major industries (i.e., PI, SI, and TI) are used as the indicators of the port development and port development to explore the dynamic coupling relationships and the inter-lagging effects between the port and the port city's economy. The YRD multi-port system is located downstream of the Yangtze River, which is the most important region connecting the world and the China mainland (see Figure 2) (Feng et al., 2020, 2021b; Huang et al., 2021; Feng et al., 2019). The YRD multi-port system mainly consists of 15 ports, in this paper we only choose nine ports as the objective, including Shanghai Port (SHP), Ningbo Port (NBP), Suzhou Port (SZP), Nantong Port (NTP), Nanjing Port (NJP), Lianyungang Port (LYGP), Jiaxing Port (JXP), Zhenjiang Port (ZJP), and Taizhou Port (Zhejiang Province) (TZZP) (see Figure 2). SHP is the world's largest container port in terms of container throughput, and NBP is ranked third in the world, but the other ports are small-scale ports. It is the fact that these ports consist of international ports and small and medium-sized ports that make the argument more convincing (Huang et al., 2022).

Figure 2 The location of the nine ports used in the analysis (see online version for colours)



Notes: In the YRD multi-port system, Lianyungang Port, Nanjing Port, Zhenjiang Port, Nantong Port and Suzhou Port belong to Jiangsu Province. Shanghai Port belongs to Shanghai City. Ningbo Port, Taizhou Port and Jiaxing Port belong to Zhejiang Province.

The data statistical description is shown in Table 1 and Table 2. The data on three major industries come from the National Bureau of Statistics (http://www.stats.gov.cn/), and the container traffic dataset comes from the China Ports year book (1999–2019) and the Ministry of Transport of the People's Republic of China (https://www.mot.gov.cn/).

4.2 Unit root test results

According to Figure 1, the unit root test is the first step to check the stationary of the time series before the ARDL bounds test. In this paper, the ADF test and PP test are applied and the results are illustrated in Table 3. It shows that the results of I(0) are different, for PP test, most of the variables are stationary, however, for the ADF test, nearly all the variables are non-stationary. But we can see that all variables are stationary at the first difference (i.e., I(1)), which sets the stage for the ARDL bounds test that follows.

Table 1 Yearly data on container traffic of the YRD multi-port system statistical description from 1992 to 2020.

	SHP	*NBP*	*SZP*	*NTP*	*NJP*	*LYGP*	*JXP*	*ZJP*	*TZZP*
Mean	1140.24	312.81	84.86	29.93	65.58	69.87	5.02	5.07	0.06
Max	4350.00	2872.00	635.50	191.00	331.00	635.50	120.40	50.00	0.14
Min	73.10	5.30	4.50	3.00	7.300	1.20	0.01	0.40	0.03
SD	1479.19	976.26	249.26	44.69	121.92	229.78	70.09	16.30	12.86

Notes: The abbreviations are as follows: SHP (Shanghai Port), NBP (Ningbo Port), SZP (Suzhou Port), NTP (Nantong Port), NJP (Nanjing Port), LYGP (Lianyungang Port), JXP (Jiaxing Port), ZJP (Zhenjiang Port), TZZP (Taizhou Port, Zhejiang Province). Mean is the mean value of the time series. Max is the maximum of the port container traffic time series; min is the minimum of the time series and SD means the standard deviation of the port container traffic time series.

Table 2 Yearly data on three major industries of the port cities in the YRD multi-port system statistical description from 1992 to 2020

Three major industries	*City*	*Mean*	*Max*	*Min*	*SD*
PI	SH	0.27	1.46	0.71	0.35
	NB	1.24	4.70	2.21	1.00
	SZ	0.72	4.02	1.61	0.98
	NT	1.71	12.51	5.08	3.26
	NJ	0.90	3.70	2.07	0.65
	LYG	3.83	9.62	6.94	1.53
	JX	1.80	16.8	6.52	4.36
	ZJ	0.99	3.17	1.85	0.50
	TZZ	2.83	14.60	5.60	3.28
SI	SH	26.59	55.60	42.27	8.79
	NB	40.98	56.74	50.62	3.54
	SZ	42.99	66.29	55.13	6.18
	NT	45.78	62.03	53.94	5.03
	NJ	35.19	52.70	45.19	5.28
	LYG	43.44	59.38	51.44	5.28
	JX	45.50	54.30	50.32	2.73
	ZJ	43.62	61.84	54.25	5.21
	TZZ	41.53	62.5	52.60	7.67

Notes: PI represents the primary industry, SI is the secondary industry and the tertiary industry. The lower abbreviations are as follows: SH (Shanghai City), NB (Ningbo City), SZ (Suzhou City), NT (Nantong City), NJ (Nanjing City), LYG (Lianyungang City), JX (Jiaxing City), ZJ (Zhenjiang City), TZZ (Taizhou City, Zhejiang Province). Mean is the mean value of the time series. Max is the maximum of the time series; min is the minimum of the time series and SD means the standard deviation of the time series.

Table 2 Yearly data on three major industries of the port cities in the YRD multi-port system statistical description from 1992 to 2020 (continued)

Three major industries	*City*	*Mean*	*Max*	*Min*	*SD*
TI	SH	43.40	73.15	57.01	9.07
	NB	40.87	57.75	47.17	3.68
	SZ	32.35	56.29	43.26	6.68
	NT	28.50	52.27	40.98	7.27
	NJ	44.66	62.81	52.72	5.20
	LYG	36.10	48.62	41.62	4.31
	JX	30.30	52.20	43.16	6.24
	ZJ	35.94	54.80	43.91	5.37
	TZZ	26.50	55.50	41.79	10.31

Notes: PI represents the primary industry, SI is the secondary industry and the tertiary industry. The lower abbreviations are as follows: SH (Shanghai City), NB (Ningbo City), SZ (Suzhou City), NT (Nantong City), NJ (Nanjing City), LYG (Lianyungang City), JX (Jiaxing City), ZJ (Zhenjiang City), TZZ (Taizhou City, Zhejiang Province). Mean is the mean value of the time series. Max is the maximum of the time series; min is the minimum of the time series and SD means the standard deviation of the time series.

Table 3 Unit root test results for the time series

Variables	*Ports*	*ADF test*		*PP test*	
		I(0)	*I(1)*	*I(0)*	*I(1)*
Container traffic	SHP	–1.9247	–4.0182**	–21.6602***	–36.478***
	NBP	–2.4708	–3.6062**	–16.7520**	–30.735***
	SZP	–1.6998	–5.1004**	–29.5009***	–40.635***
	NTP	–1.5141	–6.0734**	–24.8802***	–34.351***
	NJP	–1.911	–4.315**	–17.4709**	–28.805***
	LYGP	–2.038	–3.0972**	–24.6009***	–36.554***
	JXP	–3.5901**	–8.3094***	–27.1509***	–39.524***
	ZJP	–3.2265*	–4.6251***	–19.2351*	–36.6874***
	TZZP	–4.3303***	–9.365***	–21.5660***	–40.124***
	Cities	*ADF test*		*PP test*	
PI	SH	–3.5108**	–7.5063***	–8.2773	–26.746**
	NB	–2.6352	–4.2316***	–21.6862	–33.1401***
	SZ	–2.1251	–4.5123***	–24.9101	–38.0667*
	NT	–1.9682	–3.6874***	–27.1835	–41.5409*
	NJ	–2.6987	–4.5632***	–8.28723	–12.6643***

Notes: *, **, *** represent a rejection of the null hypothesis at 1%, 5% and 10% significance respectively, usually if the value is significant at 5%, we think this time series is stationary. I(0) denotes the time series is stationary at level, I(1) denotes the time series is stationary at first difference. The variables were tested at 5% significance, and all variables were stationary at first difference.

Table 3 Unit root test results for the time series (continued)

Variables	*Ports*	*ADF test*		*PP test*	
		I(0)	*I(1)*	*I(0)*	*I(1)*
	Cities	*ADF test*		*PP test*	
PI	LY	–2.361	–6.3261***	–21.8985	–33.6383**
	JX	–2.3015	–3.6985***	–25.1539	–38.639***
	ZJ	–1.8975	–4.5369***	–27.4496*	–42.1653**
	TZZ	–1.9361	–3.9654***	–8.36835	–12.8546*
SI	SH	–2.7738	–5.4866**	–10.864	–22.509**
	NB	–1.9531	–3.6547**	–16.7721	–25.6306*
	SZ	–2.3615	–4.5897***	–17.4919	–26.7305**
	NT	–2.1365	–6.9856***	–19.2582	–29.4297***
	NJ	–2.3124	–4.6235***	–10.877	–16.6219***
	LY	–1.9652	–4.3621***	–16.9363	–26.0159***
	JX	–2.2254	–2.6398***	–17.6631*	–27.1323***
	ZJ	–2.1635	–4.3251***	–19.4467	–29.8721**
	TZZ	–3.0695	–3.6985***	–10.9835	–16.8718**
TI	SH	–2.7932	–5.0985**	–9.902	–26.669**
	NB	–1.9864	–5.3261***	–29.5363	–45.1364***
	SZ	–2.1564	–3.9684***	–24.6304	–37.6394***
	NT	–1.9485	–5.6235***	–21.5919	–32.996***
	NJ	–1.9634	–3.9652***	–9.91388	–15.1501**
	LY	–2.0152	–4.1258***	–29.8254	–45.8149**
	JX	–2.3124	–6.3215***	–24.8715	–38.2052***
	ZJ	–2.3016	–5.3265***	–21.8032	–33.492***
	TZZ	–2.2265	–4.3574***	–10.0109	–15.3778***

Notes: *, **, *** represent a rejection of the null hypothesis at 1%, 5% and 10% significance respectively, usually if the value is significant at 5%, we think this time series is stationary. I(0) denotes the time series is stationary at level, I(1) denotes the time series is stationary at first difference. The variables were tested at 5% significance, and all variables were stationary at first difference.

4.3 ARDL results and ARDL-ECM results

Table 4 and Table 5 display the long-run relationship and the short-run relationship of the influence of the three major industries on port container traffic (ECO-oriented causality, the independent variables are the three major industries and the dependent variables are container traffic). Table 6 and Table 7 show the long-run relationship and the short-run relationship of the impact of port container traffic on the three industries (TEU-oriented casualty, the independent variables are container traffic and the dependent variables are the three major industries).

R^2 in Table 4 is the coefficient of determination, which donates the model explains the proportion of the variation. For example, the first R^2 is 0.897, implying the independent variables (i.e., PI, SI, and TI) can explain 89.7% of the total variation of the dependent variable (container traffic of SHP). F donates weather there is a cointegration, which means the independent variables have a long-run equilibrium with the dependent variable. From Table 4 we can see all F values are significant at 1% indicating that PI, SI and TI always have long-run equilibrium with SHP, NBP, SZP, NTP, NJP, LYGP, JXP, ZJP and TZZP, respectively, which means all variables have a long-run association and move together.

TEU-oriented causality donates the effects of three major industries on port container traffic, in this part, the independent variables are the corresponding port cities' PI, SI and TI, and the dependent variables are the nine ports' container traffic. For example, the data in the first column in Table 4 shows the independent variables (i.e., Shanghai City's PI, SI and TI) and Cons coefficients for the dependent variable (container traffic of SHP). The coefficient of PI for SHP is 0.010, which means that without the influence of SI and TI, as a percentage of PI increase SHP will increase by about 1.0%. That indicates PI has a negative effect on SHP. In the same way, NBP has a PI coefficient of 0.031, which means that in the absence of SI and TI effects, NBP will increase by about 3.1% as a percentage of PI increase. This suggests that PI has a positive effect on NBP. The PI coefficients for other dependent variables are empty means there is no effect of PI on port container traffic.

The SI coefficients of SHP and NBP are 0.054 and 0.062, respectively, which indicates that without the influence of PI and TI, SHP and NBP will be improved by 5.4% and 6.2% under the SI effects, respectively. For SHP and NBP, the change of container traffic caused by every% change in the SI is higher than that of the PI. Correspondingly, TI coefficients for SHP and NBP are also positive, the values are 0.058 and 0.041. The TI coefficient for SHP is greater than other ports, indicating that TI for SHP has the greatest positive impact on container transportation compared with other PI and SI.

The Cons coefficient for SZP is estimated to be –0.017, which means that when the coefficients of the independent variable are zero, SZP will decrease by about 1.7%. The PI coefficient for SZP is insignificant, and SI and TI coefficients for SZP are 0.046 and 0.026 which are all second only to SHP and NBP. The coefficient structure of NJP and LYGP is similar to SZP, and the SI, TI and Cons coefficients for NJP are 0.032, 0.015 and –0.01, respectively. The SI, TI and Cons coefficients for LYGP are 0.034, 0.011 and –0. 019, respectively. The coefficient structure is also similar to SZP and NJP. Those ports can get positive effects from SI and TI. For NTP, the only TI coefficient is –0.002, which means that a percentage increase in TI donated decreases NTP by about 0.2%. The coefficient structure of ZJP is similar to NTP, the only TI coefficient is negative, meaning TI reacts with ZJP, and the effect is –0.4%. The only TI coefficient for JXP is –0.012, and the same thing also happens with TZZP, the TI coefficient is –0.014. For NTP, ZJP, JXP and TZZP, they have one coefficient TI, and they are all negative.

The ARDL-ECM model measures how quickly the model adjusts from dynamic short-run shocks to equilibrium. The ECT_{t-1} coefficients are all statistically significant, and the p-values are all less than 1%, indicating there are short-run relationships among the variables. For example, in Table 5, ECT_{t-1} coefficient of SHP is estimated to be about –0.127, which means that if SHP is in disequilibrium with three industries, it will converge to equilibrium at the speed of 12.7% per year. Moreover, Table 5 also shows the three major industries' different influences on container traffic in the short-run relationship. We can see that not only did the current year effects (i.e., PI_t, Si_t and TI_t of the three industries have an impact on port container traffic, but the effects of the three major industries in previous years (e.g., the first lagging period of the three major industries is PI_{t-1}, SI_{t-1} and TI_{t-1} also had an impact on port container traffic, such as PI_{t-1}, SI_{t-1} and Ti_{t-1} have a positive effect on SHP, the values are 5.5%, 2.4% and 1.7%, respectively. The current period of PI, SI and TI have a positive impact on SHP, the effect values are 6.3%, 6.5% and 2.5%, respectively. At the same time, the three major industries have the second lagging period effect on SHP, the effects are 3.2%, 1.1% and 1.2%, respectively.

The impact of the current period of PI, SI and TI on NBP is all positive, that effects values are –5.4%, 9.4% and 3.6% respectively, the corresponding impact of the first lagging period of PI, SI and TI are -4.3%, 3.1% and 2.1%, respectively. SZP, NJP and LYGP have the same coefficient structure. PI does not influence SZP, NJP and LYGP container traffic. SI with its first lagging period have a pulling effect on those three ports, the current period effects are 1.4%, 3.3% and 2.6%, and their first lagging period effect is 0.5%, 1.2% and 1.6%. TI of those three ports has a positive influence on port container traffic and their first lagging period also has a positive influence on container traffic. NTP, ZJP, JXP and TZZP also have similar coefficient structures, such as the influence mainly caused by TI, the coefficients are –0.016, –0.004, –0.009 and –0.019, respectively. The only difference the first lagging period of TI has a positive impact on ZJP, and others without a lagging effect.

Table 6 and Table 7 show the long- and short-run relationship of port container traffic effects on three industries (TEU-oriented causality). TEU-oriented causality donates the effects of port container traffic on three industries, in this part, the independent variables are the nine ports' container traffic, and the dependent variables are port cities' PI, SI and TI.

In the long-run relationship of TEU-oriented, there are two ports' container traffic influence PI (i.e., SHP and NBP). The coefficients of SHP and NBP are 0.014 and –0.006, respectively. The effect of NBP on PI is slight but causes a reverse response. Increasing one unit of container traffic in SHP will increase the PI by 1.4% and that in NBP will decrease the PI by 0.6%. This fact indicates that port container traffic has few influences on PI. Regarding the influence of port container traffic on SI, five ports show a positive influence on SI. For example, SHP has the biggest positive shock on SI and with every increase in one unit of container traffic, SI will increase by 5.8%. The second influence on SI is from SZP and the coefficient value is 0.046. The third is NBP with a coefficient of 0.44. The last two are LYGP and NJP with coefficients of 0.034 and 0.032. The effect of NTP, ZJP, JXP and TZZP on SI are non-significance. For TI, all independent variables' coefficients are positive, which indicates port container traffic can accelerate the development of TI in a long-run relationship. SHP has the biggest positive influence on TI and NBP has the second effect on TI. SHP's increase in one unit of container traffic will increase the TI by 5.1% and NBP's increase in one unit of container traffic will decrease the TI by 3.9%.

Table 7 shows short-run dynamic relationships of TEU-oriented. There are two ports whose container traffic contributes to the PI, which are SHP and NBP. Moreover, Shanghai and Ningbo exist a lagging effect on PI, the lagging period is three and one, respectively. The current period of SHP for PI is 0.0095, and its lagging period coefficients are 0.0048, 0.0037 and 0.0012, respectively. NBP coefficient is negative and its first lagging period also has a negative impact on PI, their coefficients are –0.0031 and –0.0016. The other ports' container traffic does not influence PI.

Table 4 The ARDL model coefficient estimates (ECO-oriented causality)

	SHP	*NBP*	*SZP*	*NTP*	*ZJP*	*NJP*	*LYGP*	*JXP*	*TZP*
Cons	0.031	0.016	–0.017**	0.003	0.014	–0.014*	–0.019*	–0.013**	–0.003*
ln(PI)	0.010*	–0.031*	–0.036	0.021	0.021	–0.026	0.026	0.016	–0.036
ln(SI)	0.054**	0.062*	0.046**	0.016	0.006	0.032*	0.034**	–0.015	0.025
ln(TI)	0.058*	0.041***	0.026***	–0.002*	–0.004*	0.015*	0.011*	–0.012*	–0.014**
R^2	0.897	0.968	0.885	0.895	0.889	0.954	0.964	0.854	0.887
F	2.300***	2.230***	2.252***	3.036***	2.369***	3.061***	3.036***	2.649***	3.125***

Notes: *, **, *** represent a rejection of the null hypothesis at 1%, 5% and 10% significance respectively, usually if the value is significant at 5%, we think this time series is stationary. N means there is one lagging period effect but non-significance between the independent variable and dependent variables.

Table 5 The ARDL-ECM model coefficients estimates (ECO-oriented causality)

	SHP	*NBP*	*SZP*	*NTP*	*ZJP*	*NJP*	*LYGP*	*JXP*	*TZZP*
$\Delta lnPI_t$	0.063*	–0.054**	0.067	0.032	0.036	–0.007	–0.026	0.153	0.067
$\Delta lnPI_{t-1}$	0.055**	–0.043*	0.005	–0.021	0.365	0.105	0.067	0.132	0.205
$\Delta lnPI_{t-2}$	0.032**	0.058	0.006	0.036	–0.067	0.006	0.005	0.067	0.006
$\Delta lnPI_{t-3}$	–0.036	0.036	0.039	0.067	0.005	0.139	–0.008*	0.005	0.039
$\Delta lnSI_t$	0.065**	0.094**	0.014**	0.005	0.006	0.033*	0.026*	0.206	0.036
$\Delta lnSI_{t-1}$	0.024**	0.031**	0.005***	0.006	0.039	0.012***	0.016***	0.039	–0.365
$\Delta lnSI_{t-2}$	0.011*	N	0.016	0.039	0.305	0.016	0.321	0.024	0.067
$\Delta lnSI_{t-3}$	0.002	0.012	0.051	0.026	0.016	–0.021	–0.016	–0.063	0.005
$\Delta lnTI_t$	0.025***	0.036*	0.026**	–0.016*	–0.004*	0.029*	0.009**	–0.019**	–0.008*
$\Delta lnTI_{t-1}$	0.017*	0.021**	0.024*	0.015	0.031	0.021**	0.007**	0.039	0.009
$\Delta lnTI_{t-2}$	0.012*	–0.021	0.015	0.016	0.027	0.620	0.021	0.036	0.036
$\Delta lnTI_{t-3}$	–0.032	0.036	0.036	0.026	0.015	0.036	0.025	–0.365	–0.065
ECT_{t-1}	–0.127***	–0.026***	–0.071***	–0.007**	–0.006	–0.054***	–0.027***	–0.068***	–0.053***
R^2	0.964	0.854	0. 974	0.885	0.039	0.965	0.941	0.921	0.881
F	1.378	2.036	1.365	2.366	3.210	2.032	2.659	2.036	2.342

Notes: *, **, *** represent a rejection of the null hypothesis at 1%, 5% and 10% significance respectively, usually if the value is significant at 5%, we think this time series is stationary. N means there is one lagging period effect but n-significance between the independent variable and dependent variables.

Table 6 The ARDL model coefficient estimates (TEU-oriented causality).

	PI	*SI*	*TI*
SHP	0.014*	0.058***	0.051*
NBP	–0.006*	0.044**	0.039***
SZP	0.167	0.046***	0.021*
NJP	0.215	0.032*	0.012*
LYGP	0.106	0.034*	0.006***
NTP	0.039	0.005	0.006*
ZJP	0.036	00306	0.004***
JXP	–0.365	0.039	0.003**
TZZP	0.067	0.036	0.007*

Notes: In this table, PI SI and TI correspond to each port city, vice versa. For example, the first number in this table is 0.0.014, which means the coefficient of container traffic of SHP on the PI of Shanghai City.
*, **, *** represent a rejection of the null hypothesis at 1%, 5% and 10% significance respectively, usually if the value is significant at 5%, we think this time series is stationary.

There are five ports container traffic has a positive influence on SI and they all have one lagging period effect. For example, SHP with three lagging periods, NBP with two lagging periods, and SZP, NJP and LYGP have one lagging period. Moreover, the current period coefficients of SHP and NBP for SI are 0.0084 and 0.0044, indicating the container traffic of SHP and NBP can stimulate the SI's increase. The first, second and third lagging periods of SHP are decreased with the extension of the lagging period, the values are 0.0062, 0.0026 and 0.0008, respectively. The first lagging period and second lagging period of NBP are also descending compared to the current period of NBP. SZP, NJP and LYGP have one lagging period and their coefficient structure is similar. For example, those three ports' container traffic has no contribution to PI and has a beneficial influence on SI and TI. The current period coefficient of those three ports' container traffic for SI is 0.0021, 0.0031 and 0.0025, respectively. At the same time, the first lagging period coefficient of those three ports' container traffic is 0.0015, 0.0014 and 0.0006. For the left four ports, NTP, ZJP, JXP, and TZZP have no contributions to SI.

The independent variables coefficients for TI are also positive and there is a lagging period effect for SHP, NBP, SZP, NJP and LYGP. The current period coefficient of SHP for TI is 0.0069, and SH_{t-1} coefficient is 0.0066. The second lagging period of SHP is 0.0036 and the third lagging period of SHP is 0.0004. The current period coefficient of NBP with its first lagging period coefficient are 0.0036 and 0.0029. About SZP, NJP and LYGP, their lagging periods are one and all coefficients are positive. Meanwhile, the lagging period coefficients are always small than the current period. NTP, ZJP, JXP and TZZP only play a role on TI and have no lagging effect on TI. NTP has a slight effect on TI (0.0001). For ZJP, JXP and TZZP, their coefficients for TI are 0.0016, 0.0011 and 0.0024, respectively.

Table 7 The ARDL-ECM model coefficient estimates (TEU-oriented causality)

	PI	*SI*	*TI*
$\Delta lnSHP_t$	0.0095*	0.0084***	0.0069**
$\Delta lnSHP_{t-1}$	0.0048*	0.0062**	0.0066**
$\Delta lnSHP_{t-2}$	0.0037**	0.0026*	0.0036*
$\Delta lnSHP_{t-3}$	0.0012*	0.0008*	0.0004*
$\Delta lnNBP_t$	–0.0031**	0.0044**	0.0036*
$\Delta lnNBP_{t-1}$	–0.0016***	0.0023**	0.0029**
$\Delta lnNBP_{t-2}$	N	0.012	N
$\Delta lnNBP_{t-3}$	N	0.006	N
$\Delta lnSZP_t$	0.233	0.0021*	0.0032
$\Delta lnSZP_{t-1}$	0.226	0.0015**	0.0012
$\Delta lnSZP_{t-2}$	N	0.234	0.243
$\Delta lnSZP_{t-3}$	N	0.100	0.166
$\Delta lnNJP_t$	0.124	0.0031*	0.0016**
$\Delta lnNJP_{t-1}$	N	0.0014**	0.0012*
$\Delta lnNJP_{t-2}$	N	0.202	N
$\Delta lnNJP_{t-3}$	N	0.101	N
$\Delta lnLYGP_t$	0.162	0.0025***	0.0018*
$\Delta lnYGP_{t-1}$	0.213	0.0006*	0.0009*
$\Delta lnLYGP_{t-2}$	0.126	–0.426	0.224
$\Delta lnLYGP_{t-3}$	0.022	0.222	0.135

Notes: *, **, *** represent a rejection of the null hypothesis at 1%, 5% and 10% significance respectively, usually if the value is significant at 5%, we think this time series is stationary. N means there is one lagging period effect but non-significance. In this table, all R^2 are greater than 0.85, and F is also significance between each group of independent variables and dependent variables. Note: In this table, PI SI and TI correspond to each port city, vice versa. For example, the first number in this table is 0.0095, which means the coefficient of container traffic of SHP_t on the PI of Shanghai City is 0.0095.

Table 7 The ARDL-ECM model coefficient estimates (TEU-oriented causality) (continued)

	PI	*SI*	*TI*
$\Delta lnNTP_t$	0.036	0.026	0.0001*
$\Delta lnNTP_{t-1}$	–0.365	0.345	0.344
$\Delta lnTP_{t-2}$	0.017	0.117	0.126
$\Delta lnNTP_{t-3}$	0.019	0.119	0.154
$\Delta lnZJP_t$	0.033	0.013	0.0016**
$\Delta lnZJP_{t-1}$	–0.335	N	0.325
$\Delta lnZJP_{t-2}$	0.067	N	0.362
$\Delta lnZJP_{t-3}$	0.127	N	0.325
$\Delta lnJXP_t$	0.215	0.039	0.0011*
$\Delta lnJXP_{t-1}$	0.106	0.036	–0.225
$\Delta lnJXP_{t-2}$	0.039	–0.365	0.067
$\Delta lnJXP_{t-3}$	0.036	0.067	0.026
$\Delta lnTZZP_t$	–0.365	0.026	0.0024*
$\Delta lnTZZP_{t-1}$	0.067	0.345	0.215
$\Delta lnTZZP_{t-2}$	0.321	0.117	0.365
$\Delta lnTZZP_{t-3}$	0.254	0.119	N

Notes: *, **, *** represent a rejection of the null hypothesis at 1%, 5% and 10% significance respectively, usually if the value is significant at 5%, we think this time series is stationary. N means there is one lagging period effect but non-significance. In this table, all R^2 are greater than 0.85, and F is also significance between each group of independent variables and dependent variables. Note: In this table, PI SI and TI correspond to each port city, vice versa. For example, the first number in this table is 0.0095, which means the coefficient of container traffic of SHP_t on the PI of Shanghai City is 0.0095.

4.4 Robustness of the results

To check the robustness of the results, we used the VAR model to examine the cointegration between the port traffic and port cities' economy, and then we utilised the Granger causality test (Granger, 1969) to test the direction of causality between the variables. The robustness results are shown in Table 8, Table 9 and Table 10. This indicated that the lagging effects exist in the port traffic and port cities' economy, and the causality is bidirectional in SHP and NBP, which is in line with the previous results. We also can see that lagging effects of SZP, LYGP and NJP only exist in SI and TI, and the causality is bidirectional. Finally, there are some differences in the left ports. The robustness of the results shows that there were lagging effects in SI and TI, and the causality is bidirectional, which is not consistent with previous results. Therefore, the results of the Johansen cointegration test and the Granger causality test support the results of this paper.

Table 8 Johansen cointegration and Granger causality tests between port traffic and PI

	Johansen cointegration test			*Granger causality test*		
				Null hypothesis		
Ports	*Lags*	*H*	*t*	*Lags*	*TEU ⇏ PI*	*PI ⇏ TEU*
SHP	3	r = 0	6.77*	2	0.005*	0.008*
		r ≤ 1	2.34			
NBP	1	r = 0	14.44*	1	0.036*	0.048*
		r ≤ 1	4.34			
SZP	1	r = 0	12.43*	1	N	N
		r ≤ 1	4.34			
NTP	1	r = 0	6.38 **	1	N	N
		r ≤ 1	1.56			
ZJP	1	r = 0	10.60*	1	N	N
		r ≤ 1	4.02			
NJP	1	r = 0	15.14*	1	N	N
		r ≤ 1	4.33			
LYGP	1	r = 0	15.54*	1	N	N
		r ≤ 1	5.18			
JXP	1	r = 0	5.74*	1	N	N
		r ≤ 1	0.43			
TZZP	1	r = 0	13.22	1	N	N
		r ≤ 1	3.84			

Notes: *, **, *** indicate the 1, 5, and 10% significance levels, respectively. Lags reported are the number of lags in the VAR model that results in the smallest AIC. t is the Trace statistic for the null hypothesis of no-cointegration (H).

Table 9 Johansen cointegration and Granger causality tests between port traffic and SI

	Johansen cointegration test			*Granger causality test*		
				Null hypothesis		
Ports	*Lags*	*H*	*t*	*Lags*	*TEU ⇏ SI*	*SI ⇏ TEU*
SHP	3	r = 0	6.49*	2	0.016*	0.023*
		r ≤ 1	2.24			
NBP	1	r = 0	13.83*	2	0.001**	0.000**
		r ≤ 1	4.16			
SZP	1	r = 0	11.91*	1	0.032*	0.042*
		r ≤ 1	4.16			
NTP	1	r = 0	6.12*	1	N	N
		r ≤ 1	1.50			
ZJP	1	r = 0	10.15*	1	N	N
		r ≤ 1	3.85			
NJP	1	r = 0	14.51*	1	0.019*	0.031*
		r ≤ 1	4.15			
LYGP	1	r = 0	14.89*	1	0.017*	0.014*
		r ≤ 1	4.97			
JXP	1	r = 0	5.50**	1	N	N
		r ≤ 1	0.41			
TZZP	1	r = 0	12.67*	1	N	N
		r ≤ 1	3.68			

Notes: *, **, *** indicate the 1, 5, and 10% significance levels, respectively. Lags reported are the number of lags in the VAR model that results in the smallest AIC. t is the Trace statistic for the null hypothesis of no-cointegration (H).

Table 10 Johansen cointegration and Granger causality tests between port traffic and TI

	Johansen cointegration test			*Granger causality test*		
				Null hypothesis		
Ports	*Lags*	*H*	*t*	*Lags*	*TEU ⇏ TI*	*TI ⇏ TEU*
SHP	3	r = 0	5.64**	2	0.000**	0.001**
		r ≤1	1.95			
NBP	1	r = 0	12.03*	2	0.002**	0.002**
		r ≤ 1	3.62			

Notes: *, **, *** indicate the 1, 5, and 10% significance levels, respectively. Lags reported are the number of lags in the VAR model that results in the smallest AIC. t is the Trace statistic for the null hypothesis of no-cointegration (H).

Table 10 Johansen cointegration and Granger causality tests between port traffic and TI (continued)

	Johansen cointegration test			*Granger causality test*		
				Null hypothesis		
SZP	1	r = 0	10.36*	1	0.015*	0.025*
		r ≤ 1	3.62			
NTP	1	r = 0	5.32*	1	0013*	0.016*
		r ≤ 1	1.30			
ZJP	1	r = 0	8.83*	1	0.015*	0.021*
		r ≤ 1	3.35			
NJP	1	r = 0	12.62*	1	0.021*	0.006**
		r ≤ 1	3.61			
LYGP	1	r = 0	12.95*	1	0.009**	0.006**
		r ≤ 1	4.32			
JXP	1	r = 0	4.78**	1	0.036*	0.045*
		r ≤ 1	0.36			
TZZP	1	r = 0	11.02*	1	0.039*	0.003**
		r ≤ 1	3.20			

Notes: *, **, *** indicate the 1, 5, and 10% significance levels, respectively. Lags reported are the number of lags in the VAR model that results in the smallest AIC. t is the Trace statistic for the null hypothesis of no-cointegration (H).

5 Discussion

The economy of port cities is the most important factor in port development (Cheung and Yip, 2011; Haezendonck et al., 2014). Port container traffic also can accelerate the economic development of the port cities. The development of the port may help to improve the economy of the host port city. After all, the cargo flows passing through the port bring to the port city trades, information flow, financial flow, and many other value-added services (Shan et al., 2014). From the results of the causality results, we can divide the port-city relationships into four types, the first is SHP, its causality between container traffic and PI, SI and TI is bidirectional, and the effect is positive. Meanwhile, SHP container traffic has three lagging periods effect on three major industries of Shanghai City and Shanghai City's three major industries have two lagging periods effect on SHP container traffic (i.e., their inter-lagging effects between port and city are three years and two years). The Chinese reform and opening up policy built Shanghai City into a world finance centre, and the Chinese central government has been aiming to promote the construction of the Shanghai International Shipping Centre, which accelerated the development of SHP (Feng et al., 2019; Huang et al., 2021). TI is closely related to the service industry, transportation, and finance. Shanghai City has a high level of comprehensive development and its industrial structure is also dominated by the TI (see Figure 3). Consequently, the service industry is developing rapidly, and the effect of the port and port industry on the overall pulling effect of the city is obvious.

The second type is NBP which also has a bidirectional causality with three major industries, and the effect between SI, and TI is positive but has a negative bidirectional effect with PI. Meanwhile, NBP container traffic has one lagging period effect on its three major industries and Ningbo City have one lagging period effect on NBP container traffic. The lagging period of NBP for PI, SI and TI is one, which indicates that the influence of NBP on its three major industries will last for at least one year. The physical characteristics of containers are highly coordinated with heavy industry and advanced manufacturing products (i.e., SI). This is consistent with the fact that the products of these industries in Ningbo City are suitable for containerisation and NBP is beneficial from containerisation (Feng et al., 2019). The rise of containerisation has transformed the port industry, and containerisation is now the predominant method of cargo transportation worldwide. Containerisation has increased container traffic and has had a significant impact on regional economic growth (Park and Seo, 2016). In many coastal regions, container traffic has a strong positive relationship to the local economy, such as Hong Kong, Singapore and Turkey (Ng and Tongzon, 2010; Cullinane and Toy, 2000; Xiao and Lam, 2017). According to the fourteenth five-year Plan, by 2025, SHP will be built into a world-class international shipping centre. However, the Chinese central government also limited the expansion of NBP cannot at the expense of SHP traffic to ensure the success of the Shanghai International Shipping Centre (Feng et al., 2019). Therefore, the Chinese central government's strong support for SHP is not conducive to the expansion of neighbouring ports (i.e., NBP), thus restricting container traffic (Wang and Ducruet, 2012). Those strategies and policies limited the development of TI of NBP and stimulated the development of TI of SHP (see Figure 3 and Figure 4), and then had the same effects on container traffic.

Figure 3 The shanghai port container traffic and shanghai city's three industries ratio

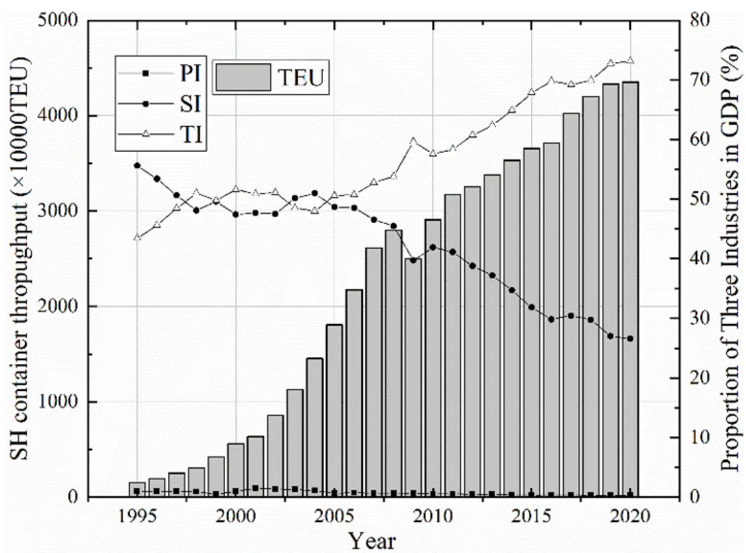
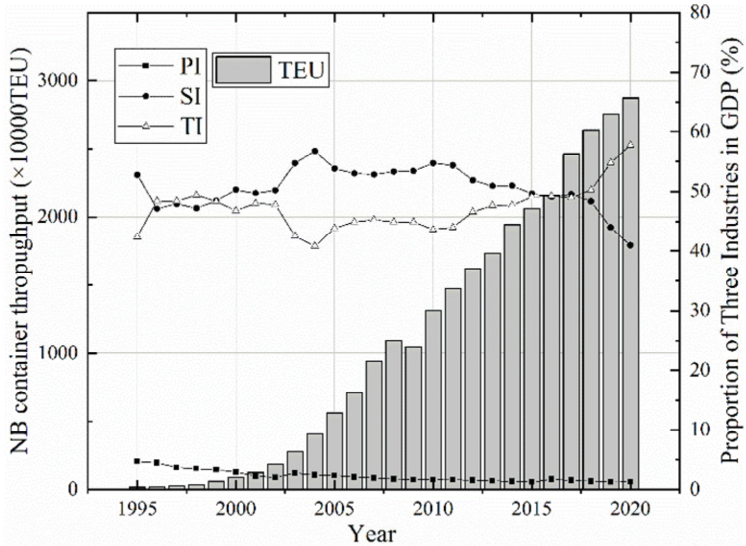


Figure 4 The Ningbo port container traffic and Ningbo city's three industries ratio



The third type is SZP, NJP and LYGP. There is a causality between container traffic and SI and TI, and their effects are positive bidirectional (see Table 4 and Table 6). At the same time, their container traffic has one lagging period effect on their three major industries, and their three major industries have one lagging period effect on port traffic (see Table 5 and Table 7). According to Cohen and Monaco (2008), port infrastructure contributes to the regional output of manufacturing, which is in line with the results in this paper. At the same time, container ports play a key role in manufacturing in global trade (Park and Medda, 2018), which is also consistent with the results in this paper. According to the definition published by The World Bank, PI involves the production of raw materials and has traditionally been the backbone of the economy of many port cities and SI involves the processing of raw materials and the manufacturing of goods. TI is closely related to the service industry, transportation, and finance. Container ports have been crucial in facilitating the export of raw materials to other countries and the availability of container transport has made it easier for manufacturers to export their products to other countries. The development of container ports has had a significant impact on the growth of the TI. Container traffic has increased the demand for various services, such as warehousing, transportation, and logistics (Lee and Shin, 2020; Shan et al., 2014). LYGP is mainly engaged in container cargo as well as bulk and general cargo. It is the biggest port in Jiangsu Province and the east bridgehead of the new Eurasian Continental Bridge. Meanwhile, LYGP has good rail connections with the hinterland. This fact takes advantage of the agglomeration effect of people, logistics, information, and capita. The agglomeration effect of the port economy has a strong radiating effect, which will greatly drive the development of the regional economy, effectively promote the adjustment of local economic and industrial structure, and enhance the regional competitiveness of Lianyungang City. SZP is the joint port of the Shanghai International Shipping Centre, located at the intersection of the two main axes of the Jiangsu Riverside Industrial Belt and the Coastal Open Belt. In terms of the port container throughput, SZP is the seventh port since 2018. And Suzhou City is also famous for the manufacturing and metal smelting industry in China, as we mentioned before, manufacturing is suitable for containerisation. It is excellent for Suzhou City to develop foreign trade. And due to its good inland transportation system, the water-to-water transhipment rate is low (Guo et al., 2020).

The last type is ZJP, JXP, TZZP and NTP, whose container traffic only has causality with TI (see Table 4 and Table 6), and there is no lagging effect in their dynamic relationship. The growth of TI has created many new jobs in port cities, such as truck drivers, warehouse workers, and logistics specialists. These jobs have contributed to the growth of the local economy and have helped to stimulate the development of TI. At the same time, SZP and NTP are located at the estuary of the Yangtze River and are important river iron ore transhipment hubs, leading transportation services and in turn driving the growth of the TI. ZJP and NTP as transhipment ports located downstream of YRD, and the transhipment rates are about 97% and 99%, respectively (Yang et al., 2017). A Port with a high transhipment rate always has less related to the port city's economy (Cheung and Yip, 2011; Slack and Gouvernal, 2016), this point is also consistent with the results in this paper. The influence of ZJP and NTP on the three industries only exists in the current period. TZZP and JXP as the feed ports of NBP and their main cargo type tend to be homogeneous with NBP. The goods are mainly construction materials, coal, automobiles, cement, steel, petroleum, electromechanical and other seven categories, accounting for more than 90% of the total throughput over the years.

From the perspective of managerial insight, multiple stakeholders have different interest orientations for the dynamic relationships and inter-lagging effects of ports and port cities. For example, policy makers related to port and city can better understand the port-city development pattern, and then ensure the precise implementation of policies. On the other, the investors may assess the prospective profitability of the invested target port and city to confirm whether to increase the investment, which would be smart enough to avoid the capacity surplus problem. As the government, they can determine how to plan the local economic structure to properly integrate with the port development to ensure the long-term prosperity of their territory. Therefore, managerial implications, the methodology and the results may provide valuable information for building strategy plans, resource assignments and optimisation, and then improve the ports and cities' management efficiency.

6 Conclusions

The contribution of this paper compared to other literature is constructing a useful and complete framework to explore the dynamic coupling relationships and the inter-lagging effects between the port and port city, especially in exploring and analysing the relationships between port traffic and the three major industries of the port cities. An empirical analysis of the YRD multi-port system was performed for illustration and verification purposes, but the framework we proposed is also useful and applicable to other ports and port cities worldwide. The findings show that port container traffic and the economy of the port city have significant interaction for both short- and long-run relationships, but different-scale ports have different port-city relationships and different inter-lagging effects.

Furthermore, the port-city relationships in the YRD multi-port system can be divided into four types, The first is SHP, and the ECO-oriented and TEU-oriented effects have obvious lagging effects, with lagging periods of two and three, respectively. In the long-run relationship, SHP has positive bidirectional interrelationships with its PI, SI and TI. The second type is NBP. NBP has one lagging period for the ECO-oriented and TEU-oriented effect in the short-run relationship. In the long-run relationship, NBP has a positive bidirectional effect with SI and TI but has a negative bidirectional effect with PI. The third is SZP, LYGP and NJP, the lagging effect only exists in SI and TI, and their lagging periods are one in short-run relationships. In the long-run relationship, their container traffic has a positive bidirectional relationship with SI and TI. The last group is NTP, ZJP, JXP and TZZP, whose container traffic has a positive effect on TI, however, TI has a negative impact on container traffic in long-run relationships. There is no lagging effect no matter for the ECO-oriented effect or TEU-oriented effect in short-run relationships.

Finally, the results also indicated that TI has the closest relationships with port development, SI is second only to the TI, and PI is the last one that has less connection with port development. Meanwhile, with the extension of the lagging periods, the positive effect and negative effects are always declining. In terms of methodology, this paper proposed a complete analytical framework to explore the dynamic coupling relationships and the inter-lagging effects between economic indicators of the port city and port container traffic. The case of the YRD multi-port system was performed for illustration and verification purposes, but the framework we proposed is also useful and applicable to other ports and port cities worldwide. In this sense, the empirical analysis in this paper can help policymakers to better understand the dynamic relationship between the economy of the port city and port container traffic, meanwhile, it also provided a new perspective for related researchers to enrich the understanding of port-city interaction.

However, during the empirical study, this paper only takes into account the three major industries of the port city and port container traffic, which lacks comprehensiveness and does not consider the external factors such as trade and policies that influence the port system. In future research, we will build a more comprehensive index system of the port-city system to further improve the scientific accuracy of the research on the lagging effect of port-city coordination.

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