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Impact of Hinterland Manufacturing on the Development of Container Ports: Evidence from the Pearl River Delta, China

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Abstract: Container ports and hinterland manufacturing are two important forces of the local participation in economic globalization. This study, taking the Pearl River Delta (PRD), China with an export-oriented economy as an example, applies Huff and panel regression models to evaluate the impact of hinterland manufacturing on the development of container ports during the period of 1993–2019. The results show that 1) the spatial patterns of hinterlands for hub ports help to determine the distribution range and scale of economic variables that affect port throughput; 2) the hinterland's gross manufacturing output has universally positive influence on port throughput, wherein export-oriented processing and the entire manufacturing industry have significantly positive impact on port throughput in 1993–2011 and 2001–2019, respectively; 3) the two internal structural factors related to an export-oriented economy, labor-intensive sectors and foreign-funded terminals, have positively moderate the direct influence of hinterland manufacturing on port throughput. Our results highlight the importance of local context in understanding port-manufacturing relationship in developing economies. Based on our findings, policy implications are further proposed to enhance port network organization in PRD.

Keywords: container ports; hinterland manufacturing; local development context; Huff model; panel regression model; Pearl River Delta (PRD), China

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1 Introduction

Container ports and manufacturing have long played key roles in local participation in economic globalization. Early studies on production networks have revealed that manufacturing transfer and supply chains are highly functionally integrated and geographically dispersed, forming complex transnational networks. It is not until the 2000s that the logistical foundation facilities, particularly container ports and their hinterland transportation organizations, have attract sufficient scholarly attention (Ducruet et al., 2019 ; Ng, 2013). Currently, more than 80% of merchandise trade (e.g., raw materials and products) is transported by sea (The World Bank, 2024), and maritime container traffic has experienced even faster growth than the GDP, exports, and population since the 1970s (Rodrigue et al., 2016). Intuitively, the performance of container ports seems to be positively associated with manufacturing.

However, the question of whether or not manufacturing has a significant impact on port development still remains to be answered. So far, findings from the existing empirical studies are rather mixed (Amdaoud et al., 2022; Fageda and Gonzalez-Arega, 2017). One import-

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ant reason for this contention may lie in the differences in the local development contexts. Focusing on the port-city economic relationship, a series of studies have analyzed the spatial relationship between port activities and local industries. Based on observations of post-industrially developed economies, Hoyle's (1989) port-city interface evolution model points out that after the initial establishment and subsequent strengthening of ports, the port-city economic relationship will separate and weaken to varying degrees (Dadashpoor and Taheri, 2022; Li and Liu, 2022). In this model, owing to traffic and space constraints, port activities move out of the central location of the city and separate from city's economy activities. The original waterfront is then redeveloped with a low degree of industrialization. Follow-up case studies under Western economy context also show that the industrial benefits generated by ports appear more outside the cities (Monios and Wilmsmeier, 2012; Chen and Lam, 2018) and that modern ports and urban industry are no longer interrelated complexes (Gripaios and Gripaios, 1995). By contrast, researches on developing economies, such as Asia (Lee et al., 2008) and the Middle East (Akhavan, 2017), have come to some conclusions that are different from the classic Western port-city interface evolution model. Asian hub port cities are usually global industrial centers and ideal locations for multinational companies to invest in manufacturing. As port activities expand downstream, the old port area located upstream becomes highly compatible with diversified urban activities (Lee et al., 2008); the new port area is positioned as a logistics and industrial complex (Liang et al., 2012; Wang and Ducruet, 2012). During this evolution, the port-adjacent industry experiences spatial restructuring and upgrading, and thereby leading to complex interrelationships between modern ports and urban industry (Guo and Han, 2013; Wang et al., 2021). Moreover, in developing countries of a usual export-oriented economy, the port-manufacturing relationship is uncertain due to the market orientation and industrial upgrading. Previous evidence suggests that the port-manufacturing relationship may also be moderated by internal structure factors (related to export-oriented economy) of manufacturing and the container ports (Wang and Slack, 2000; Ducruet and Jeong, 2005).

Another possible reason lies in delineating a port's hinterland. Considering that each port no longer develops independently but exists in a complex multi-port network, researchers call for further studies on the relationship between container port and hinterland manufacturing based on multi-port case instead of based on an independent one. Owing to containerization at a global scale and the rise of transshipment hub ports, there is a significant difference in the hinterlands between hub and feeder ports. With reference to Kautz's sea port location theory, hinterland economic performance plays a significant role in the rise and decline of container ports (Yang et al., 1986). Existing studies based on the Yellow Sea Rim (Lee and Rodrigue, 2006), and the Pearl River Delta (Fu et al., 2010; Zhang et al., 2015) have confirmed the impact of manufacturing transfer and supply chain on the reconstruction of a regional port system. However, other cases also show that the transfer of cargo in the port system is not due to the spatial distribution of economic activities, but to the local development contexts, such as geopolitics (Ducruet et al., 2009). In addition, by comparing and summarizing the economic correlations between multiple ports and the region that these ports are located, scholars have identified regional port clusters with high concentrations of manufacturing according to the port cargo structure and local economic structure, supplemented by classification methods (Ducruet and Itoh, 2016; Amdaoud et al., 2022). Given that the hinterlands of hub ports often cover surrounding cities and overlap, scholars have proposed techniques of mathematical models, such as the Huff model (Jiang and Zhang, 2013), for hinterland segmentation.

To this end, this study evaluates the impact of hinterland manufacturing on the development of container ports in the context of an export-oriented economy, taking the Pearl River Delta (PRD), China as an example. Specifically, this study develops the following sub-questions: 1) in terms of direct influence, do hinterland manufacturing output generally promote the growth of container ports? Are there differences in the influences between export-oriented processing and the entire manufacturing industry? 2) Whether internal structural factors related to export-oriented economy in manufacturing industries (i.e., labor-intensive sectors) and container ports (i.e., foreign-funded terminals) moderate such direct influence? Methodologically, this study integrates Huff and panel regression models to supplement the shortcomings of existing studies that mainly focus on independent gateway hub ports, with little attention payed to the relationship between multilevel ports and hinterland manufacturing. In so doing, we expect to enhance our understandings of logistic network organization of manufacturing and the local factors that impact such network. Additionally, this study provides a reference for enhancing port network organization in PRD under market orientation and upgrading of manufacturing since the new century.

2 Materials and Methodology

2.1 Study area

The PRD contains nine port cities (Fig. 1). Since the reform and opening up, relying on the geographical advantage of its adjacency to Hong Kong and Macao, as well as favorable opportunities for Hong Kong's manufacturing and port & shipping industries to invest in the mainland, the PRD has rapidly participated in the international division of labor through its export-oriented economy. In addition, a multicore container port system with distinct levels of hub and feeder ports has been formed and ranked among the three major port systems in China. Owing to its unique development context and driving force, the evolution of port systems in the PRD has attracted widespread scholarly attention (Wang, 1998; Wang and Slack, 2000; Wang et al., 2012; Liu et al., 2013; Cheng and Wang, 2015). Early researches point out that, similar to other Asian port regions, the PRD relies on limited intermodal transport corridors to connect ports with export-oriented production bases (Wang and Slack, 2000; Ducruet and Jeong, 2005). However, there is a lack of discussion on the impact of hinterland manufacturing on port container throughput and the corresponding response of the port & shipping industry in the PRD under the market orientation and upgrading of manufacturing since the new century.

2.2 Analytical framework

Fig. 2 illustrates the framework for the empirical analysis in this study. After determining the hinterlands of hub ports and feeder ports based on the Huff model, and controlling for other variables affecting throughput, we tested whether there is a statistically significant relationship between port container throughput and hinterland manufacturing output during the period of 1993–2019 with the panel regression method. This significant sign can indicate that manufacturing activities in each hinterland provide a direct supply of goods for container ports; in other words, hinterland manufacturing has a universal impact on port development at the regional level.

2.3 Huff model and port hinterland

The delineation of a port hinterland (the source of container cargo) is a prerequisite for discussing the relationship between port and manufacturing. By delineating

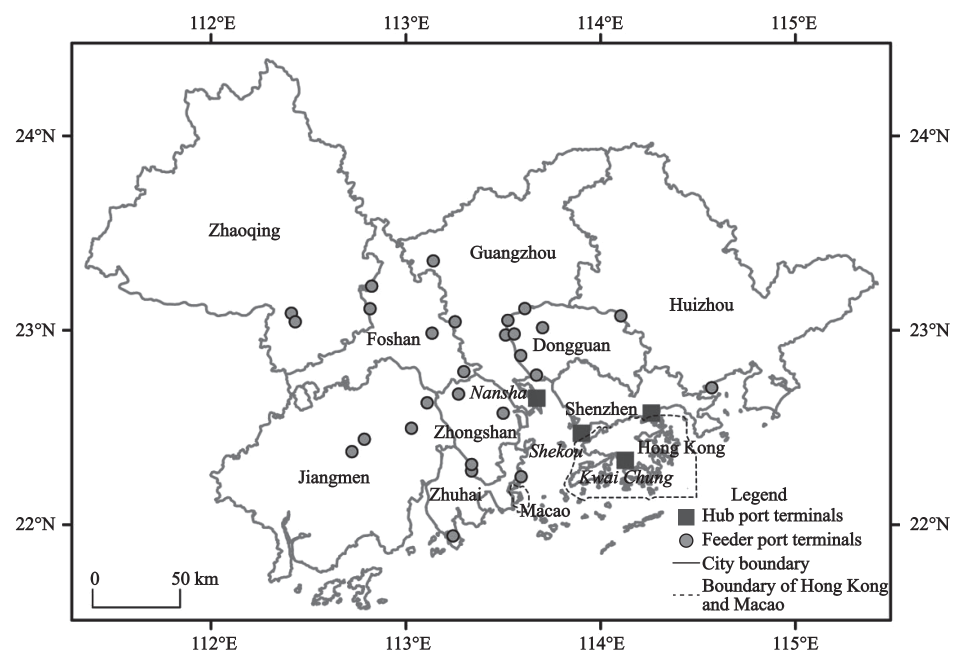

Fig. 1 Distribution of port cities and container terminals in the Pearl River Delta (PRD), China

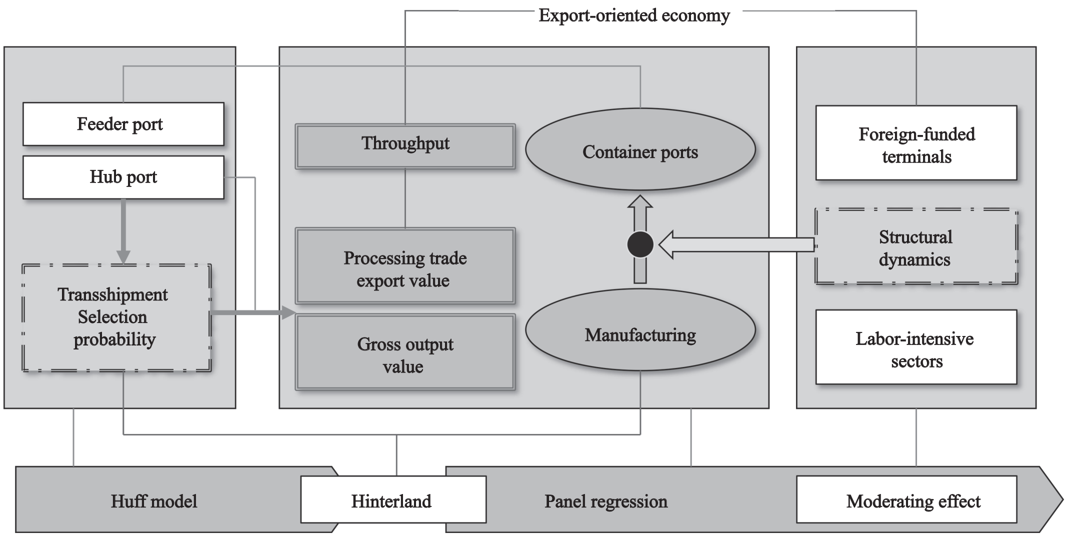

Fig. 2 Analytical framework for determining port system and investigating impact of hinterland manufacturing on container port development

the port hinterland, we can further determine the distribution range and scale of economic variables that affect port throughput, which can be used as the input of the subsequent regression analysis to reduce the misestimation risk resulting from using the port city's administrative range as a statistical unit. Given its multi-core structure, there are not only significant differences between the hinterlands of hub ports and feeder ports. For example, according to our survey, the goods supply of Nansha Terminal in Guangzhou Port covers the entire western PRD. In contrast, most cargo containers in feeder ports, such as the Dongguan and Foshan ports, mainly originate from port cities. Coinciding hinterlands also exist among hub ports. In a traditional Huff model, a region can be divided into several hinterlands that attribute to hub ports for cargo transshipment (Jiang and Zhang, 2013).

As such, according to whether each port terminal has operated ocean liner routes to undertake the transshipment function, the PRD port system includes three hub port cities: Guangzhou (*Nansha Terminal*), Shenzhen (*Yantian Terminal and Shekou Terminal*), and Hong Kong (*Kwai Chung Terminal*). The remaining ports are classified as feeder ports. Considering the structural evolution of the port system, although Hong Kong is not included in our study area, it has occupied a monopoly position in entrepot trade in the PRD and even South China since the 1960s; it has been the only hub port city in the region until the early 1990s (Cheng and Wang, 2015). Therefore, it was listed as an alternative port for transshipment in our model. The formation of a multi-core structure in the port system stems from the following two events: 1) Maersk, a big foreign-invested container terminal enterprise, acquired a 10% stake in *Yantian Terminal* of Shenzhen in 1994 and used it as a new hub port in the shipping network (Wang et al., 2012), and 2) Guangzhou completed the first-stage project of the *Nansha Terminal* in 2004 and began to operate international liner routes. Considering a possible time lag on carrier's port selection, the year 1995 and 2005 were taken as the starting years for Guangzhou and Shenzhen to become hub port cities according to the above-mentioned landmark events, respectively.

The hinterland is divided into two parts for a hub port: the city where the port is located and other feeder port cities. The probability, P_{ij}, that feeder port city i selects hub port j for transshipment was calculated using Eq. (1):

$$P_{ij} = \frac{U_j}{\sum_{j=1}^{n} U_j} = \frac{S_j d_{ij}^{-\beta}}{\sum_{j=1}^{n}\left(S_j d_{ij}^{-\beta}\right)} \tag{1}$$

where U_j is the utility of hub port j, n represents the total number of hub ports, S_j is the comprehensive influence measured by the hub port influence index system, d_{ij} is the time distance between the feeder port city and hub port city, and β is the distance friction coefficient, which generally takes a value of 2. According to the previous setting, Guangzhou and Shenzhen acquired the hinterlands formed by other feeder port cities in 2005–2019 and 1995–2019, respectively. In contrast to the original Huff model (Jiang and Zhang, 2013), the hinterland division results in this study represent each port's potential largest range of cargo source, highlighting the difference of the cargo transshipment capacity between hub and feeder ports.

The hub port influence index system (S) aims to reflect the port service capacity other than the economy status of the port city. Referring to the indicators (Jiang and Zhang, 2013) and considering the comparability of data between PRD and Hong Kong ports, three indicators, namely the container throughput (s_1), number of berths above 10 000 t (s_2), and number of international shipowners stationed (s_3), were selected to comprehensively measure the influence of a hub port. The data for s_1 and s_2 were derived from the China Ports Yearbook (https://data.cnki.net/yearBook/), whereas s_3 that comprises shipowners ranked in the top 20 global shipowner capacities in 2021 were collected from *Alphaliner* (https://alphaliner.axsmarine.com/PublicTop100/.2021-12-30). The service networks of these shipowners in Hong Kong, Shenzhen, and Guangzhou were checked through *Qichacha* (https://www.qcc.com/. 2021-12-10), an enterprise search website, and the official websites of these shipowners. If a headquarters, subsidiary, or office are established in hub port city j in a certain year, the value of the s_3 indicator in subsequent years will increase by 1. Finally, the three indicators were normalized separately, and their comprehensive influence was calculated based on an even weight.

For distance d_{ij}, previous studies on PRD port system have shown that the land trucking cost is one of the core factors affecting hub port's hinterland size (Wang and Slack, 2000). Thus, we measured the shortest path in the network by travel time from the county administrative center of the feeder port city to the deep-water terminals of the hub ports: *Nansha Terminal*, *Shekou Terminal*, *Yantian Terminal*, and *Kwai Chung Terminal*. As for Dongguan and Zhongshan, we divided the city area into sub-districts according to Dongguan City Master Plan (2016–2030) and Zhongshan City Master Plan (2010–2020) respectively since these two cities have no county-level administrative districts. The results for multiple counties in the same feeder port city were averaged and combined. The road network data were obtained from the Global Biodiversity Model of the Policy Support Research Institute (https://www.globio.info/resources/). Owing to data availability, only road network data of 2015 was collected. Thus, the shortening of time and distance caused by road construction has not been considered in this measurement. The road network comprises the first four levels of road, namely highways and primary, secondary, and tertiary roads, with speed limits to 100, 80, 60, and 40 km/h.

Based on the probability, P_{ij} obtained from Eq. (1), the value for each explanatory variable of the hinterland of hub port j, Y_j, was calculated using Eq. (2),

$$Y_j = X_j + \sum_{i=1}^{m} P_{ij} X_i \tag{2}$$

where X_j is the value for a certain explanatory variable of the city in which hub port j is located, X_i is the value for the same variable of the city in which feeder port i is located, and m is the total number of feeder port cities in the hinterland. In short, Y_j is used for reflecting hinterland's status of hub port j.

2.4 Panel data regression

Panel regression model was adopted to test the relationship between port container throughput and hinterland manufacturing in PRD during the period of 1993–2019. The container throughput (CT) of each port was set as the explained variable, which was caculated by aggregating the throughput of all terminals located in the port city. In response to the special local development context, i.e., PRD's export-oriented economy, two explanatory variables, the gross manufacturing output value (MN) and processing trade export value (PE), were used to represent the entire manufacturing industry and its export-oriented components, respectively. We expect the signs of the two explanatory variables can reveal the port-manufacturing relationship evolution that are caused by shifts in the market orientation and industrial upgrading. The baseline model can be presented as:

$$CT_{pt} = \beta_1 MN_{pt} + \beta_2 PE_{pt} + \sum_{k=1}^{h} \beta_k CV_{kpt} + \varepsilon \tag{3}$$

where CT_{pt} is the container throughput of port p in year t. CV_{kpt} are a set of control variables and h is the number of these variables. β_k means the regression coefficient of variable k. ε is the error term.

Given that data on manufacturing exports by city during the study period are unavailable, the sum of the export value of processed, supplied, and imported materials from China Customs Database was used as a proxy of PE_{jt}. With reference to previous studies (Ducruet and Lee, 2006; Guo et al., 2015), we used population (*PP*), retail sales of social goods (*RT*), fixed asset investment (*IV*), and freight turnover (*FT*) as control variables. The natural logarithms for explained, explanatory, and control variables were used to reduce the effects of heteroscedasticity.

To test the moderating effects of internal structural factors related to export-oriented economy, two moderating variables, i.e., labor-intensive sectors (*LB*) and foreign-funded terminals (*TM*), and their interaction terms with explanatory variables were further introduced in the following analysis based on the baseline model. These variables represent the two key areas (manufacturing and port & shipping industry) of foreign investment in China (not including Hong Kong, Macao and Taiwan) when the PRD became rapidly embedded in the global production network after the reform and opening up, which may affect the logistics demand generated by export-oriented processing. To add the interaction terms between modering variables and two explanatory variables, *MN* and *PE*, into different sets of models, the new regression models were written as Eqs. (4) and (5).

$$CT_{pt} = \beta_1 MN_{pt} + \beta_2 PE_{pt} + \beta_3 MN_{pt} \times MV_{pt} + \beta_4 MV_{pt} + \sum_{k=1}^{h} \beta_k CV_{kpt} + \varepsilon \quad (4)$$

$$CT_{pt} = \beta_1 MN_{pt} + \beta_2 PE_{pt} + \beta_3 PE_{pt} \times MV_{pt} + \beta_4 MV_{pt} + \sum_{k=1}^{h} \beta_k CV_{kpt} + \varepsilon \quad (5)$$

where MV_{pt} are the moderating variables of port p in year t, which refer to *LB* and *TM* in this article. The meanings of other symbols are the same as that of Eq. (3).

All moderating variables were centralized within groups before constructing intersection terms. Other terms are defined as above. Note that all explanatory, control, and moderating variables were calculated based on Eq. (2). And to avoid multicollinearity issues, only one interaction term was added in each model. Table 1 summarizes the definition and data sources for each variable. As for the variable *TM*, the China Ports Year Book and the official websites of the municipal transportation bureaus provide a directory of container terminal enterprises, and the Qichacha website provides information on these enterprises' establishment year and

Table 1 Variable definitions and data source

Category	Definition		Data source
Explained variable	Container throughput (*CT*)	LN (container throughput of the ports)	China Ports Year Book (https://data.cnki.net/yearBook/)
Explanatory variables	Gross Manufacturing output value (*MN*)	LN (gross manufacturing output value of hinterlands)	Guangdong Statistical Yearbook and Statistical yearbooks of each municipalities (https://data.cnki.net/yearBook/)
	Processing trade export value (*PE*)	LN (processing trade export value of hinterlands)	Guangdong Statistical Yearbook and China Customs Database (http://microdata.sozdata.com/#/custom_index)
Control variables	Population (*PP*)	LN (resident population of hinterlands)	Guangdong Statistical Yearbook (https://data.cnki.net/yearBook/)
	Retail sales of social goods (*RT*)	LN (retail sales of social goods of hinterlands)	
	Freight turnover (*FT*)	LN (freight turnover of hinterlands)	
	Fixed asset investment (*IV*)	LN (investment in fixed assets of hinterlands)	
Moderating variables	Labor-intensive sectors (*LB*)	Proportion of labor-intensive sectors in gross manufacturing output value of hinterlands / %	Guangdong Statistical Yearbook
	Foreign-funded terminals (*TM*)	Proportion of registered capital of each port city's foreign-invested container terminal enterprises in PRD / %	China Ports Year Book, official websites of each municipal transportation bureaus (https://gwj.gz.gov.cn/, https://jtys.foshan.gov.cn/, *et al.*), and Qichacha (https://www.qcc.com/)

Notes: LN means the logarithmic form of the raw data for the variable. *LB* is measured following Yang et al., 2018. Considering the large number of municipal transportation bureaus websites, only two are listed here registered capital.

3 Results

3.1 Overview of container port and hinterland manufacturing development

3.1.1 Hinterlands division in the PRD

The probabilities of feeder port cities selecting Guangzhou or Shenzhen for containers transshipment, according to the Huff model results, are shown in Fig. 3. The year 1995 when Shenzhen became a hub port was chosen as the starting time. Considering the overall planning of major construction projects and productivity layout at the national level every five years, that is, the ‘five-year plan’, the subsequent interval is set to five yr (with the exception of 2015–2019). Only the selection probability of Shenzhen existed in PRD in 1995 and 2000. Since 2004 when Guangzhou became a hub port, the hinterlands were divided between Guangzhou and Shenzhen in 2005, 2010, 2015, and 2019. Considering the historical function of Guangzhou as an import and export port in South China and one of the first ports to build container terminals in China (not including Hong Kong, Macao and Taiwan of China after the reform and opening up (Wu et al., 2013), although it developed into a hub port later than Shenzhen, we still assumed that the container cargo generated by Guangzhou and Shenzhen are transported by their own ports. Thus, the selection probabilities of Guangzhou city to Shenzhen and to Guangzhou hub ports were set as 0 and 1, respectively, and vice versa.

Until the mid-1990s, Shenzhen was less attractive to feeder port cities because of its inferiority to Hong Kong in terms of scale and incoming shipowners. The probabilities of all feeder port cities selecting Shenzhen for transhipment were no more than 30%. From 1995 to 2000, the attraction of Shenzhen to the eastern PRD surpassed that of Hong Kong. Since 2005, the attraction of Guangzhou to each feeder port city has increased annually, with significant enhancement occurred during 2010–2015. Generally, the regional distribution of the selection probability remained stable between 2015 and 2019. By the end of 2019, Guangzhou and Shenzhen formed a relatively balanced competitive pattern, with the eastern and western areas of the PRD as their main hinterlands, respectively. For example, the selection probabilities of Zhuhai, Foshan, and Zhongshan to Guangzhou were greater than 60%, whereas that of Huizhou to Shenzhen was greater than 60% in 2019.

3.1.2 Container ports and manufacturing development in the PRD

Fig. 4 presents development trends of container ports and hinterland manufacturing in the PRD. During 1993–2019, *CT* of the PRD’s port system grew from 820 000 TEU to 63.82 million TEU. The two hub port cities, Shenzhen and Guangzhou, had occupied a major share of the entire PRD, with the proportion rapidly rising from approximately 45% to over 80% during 1993–2005, although the proportion gradually declined after 2014. This result implies the considerable difference of hinterland range between the hub and feeder ports.

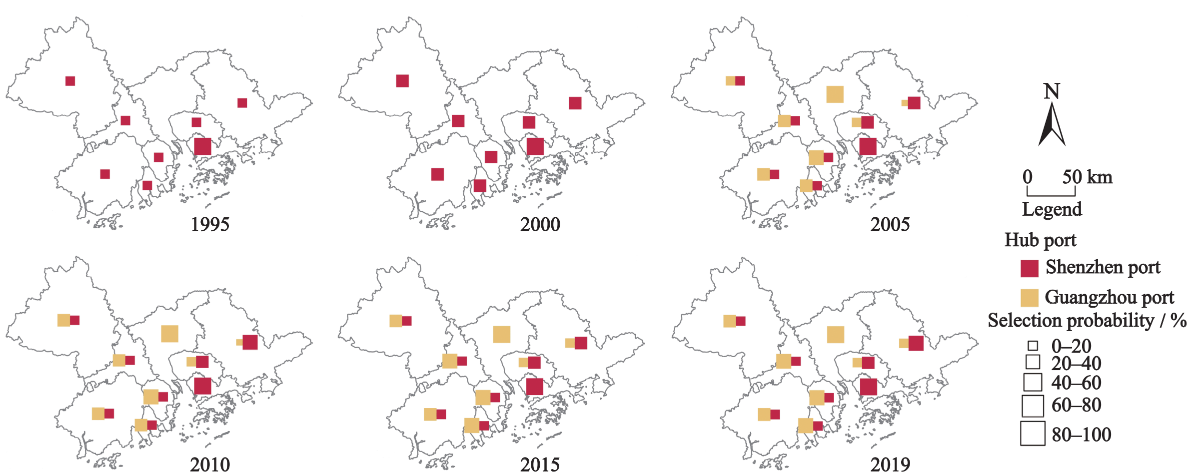

Fig. 3 Selection probability of each hinterland city selecting a hub port for containers loading, unloading or transshipment in the Peral River Delta, China

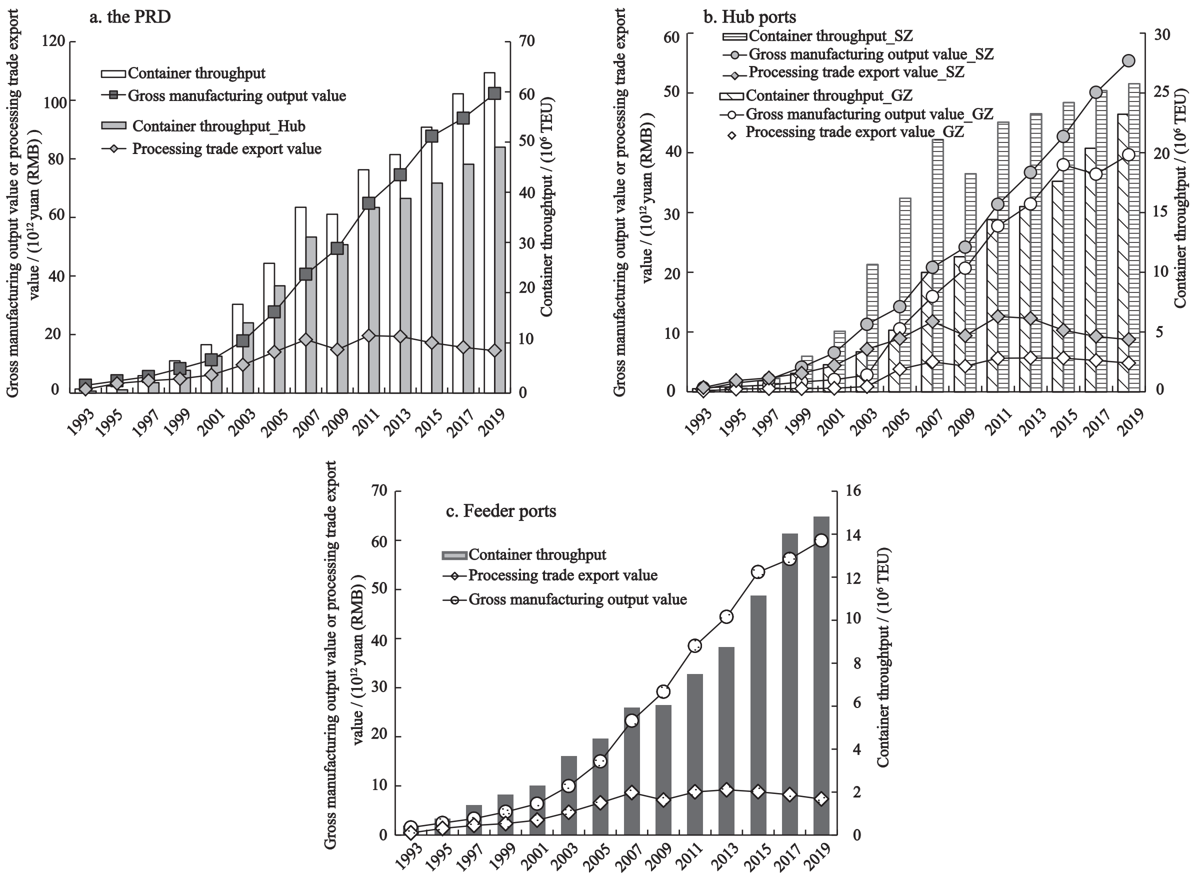

Fig. 4 Development trends of container ports and hinterland manufacturing in the Pearl River Delta (PRD), China. 'Hub', 'Feeder', 'GZ', and 'SZ', indicate the hub port, feeder port, Guangzhou, Shenzhen, respectively. *MN* and *PE* were calculated at the hinterland scale

Regarding *MN* and *PE* in PRD, their value grew from 265 and 129 billion yuan (RMB) in 1993 to 102 277 and 1448 billion yuan, respectively. Generally, *CT*, *MN*, and *PE* kept consistent growth trend in 1993–2008. However, after 2008 financial crisis, *PE* begun to fluctuate and deviate from the general growth trend of *CT* and *MN* (Fig. 4a). Focusing on Guangzhou and Shenzhen, the two port cities, have shown similar growth trends of *MN* and *PE* compared to the growth trends in the PRD. *MN* and *PE* of Shenzhen have been always higher than that of Guangzhou during the study period (Fig. 4b). For the remaining seven feeder ports, the growth trends of *CT* and *MN* are also similar to that of PRD and hub ports. *MN* and *PE* of the seven feeder ports are equivalent to about 60% and 50% to that of PRD, albeit with minor fluctuations during 1993–2019.

3.2 Impacts of hinterland manufacturing on container port development

3.2.1 Direct Influence

Prior to estimating the baseline panel regression model, we tested for stationarity and cointegration issues. The results showed that original panel dataset were unstable. Thus, differencing, a process of subtracting the current value of a time series from its previous one, was adopted. Meanwhile, given that unobserved variables that impact port throughput may exist, individual fixed effects models were used as suggested by the Hausman test. Table 2 summarizes the results of the baseline panel regression model (Model 1) and panel regression models with interaction terms (Models 2–5). The goodness of fit (R^2) of all five models is high, indicating that explanatory, control, and moderating variables of the hinterlands based on the Huff model can largely predict *CT* of ports.

As shown in Model 1, *MN* has significantly positive impact on *CT* with the largest magnitude, indicating that hinterland manufacturing has the largest impact on port container throughput. Although the coefficient of *PE* is above 0, the sign is not significant. The positive relationship between *MN* and *CT* also suggests that local

Table 2 Regression results of panel data in the Pearl River Delta in China from 1993 to 2019

Explained variable container throughput	Model 1	Model 2	Model 3	Model 4	Model 5
	Coef.(*t*)	Coef.(*t*)	Coef.(*t*)	Coef.(*t*)	Coef.(*t*)
Gross manufacturing output value	0.82(4.51)***	0.71(3.81)***	0.71(3.86)***	0.83(4.60)***	0.82(4.59)***
Processing trade export value	0.12(0.89)	0.02(0.11)	0.01(0.05)	0.14(1.00)	0.14(1.00)
Population	0.31(1.36)	0.33(1.43)	0.38(1.66)*	0.26(1.13)	0.26(1.16)
Retail sales of social goods	−0.33(−1.81)*	−0.25(−1.36)	−0.31(−1.75)*	−0.37(−2.05)**	−0.35(−1.99)**
Freight turnover	0.16(1.91)*	0.18(2.13)**	0.18(2.07)**	0.17(2.02)**	0.16(1.95)*
Fixed asset investment	0.15(1.18)	0.22(1.69)*	0.27(2.02)**	0.18(1.48)	0.18(1.50)
Gross manufacturing output value × Labor-intensive sectors	–	0.02(2.58)**	–	–	–
Processing trade export value × Labor-intensive sectors	–	–	0.03(2.84)***	–	–
Labor-intensive sectors	–	0.00(0.09)	0.00(0.21)	–	–
Gross manufacturing output value × Foreign-funded terminals	–	–	–	0.02(1.19)	–
Processing trade export value × Foreign-funded terminals	–	–	–	–	0.04(1.97)**
Foreign-funded terminals	–	–	–	0.02(3.04)***	0.02(3.43)***
Constant	−2.47(−3.39)***	−2.62(−3.56)***	−2.91(−3.88)***	−2.69(−3.73)***	−2.72(−3.79)***
Individual fixed effect	Yes	Yes	Yes	Yes	Yes
Observations	243	243	243	243	243
R^2	0.83	0.84	0.84	0.84	0.84
F	38.91***	34.28***	34.94***	31.91***	31.50***

Notes: 'Coef' means the regression coefficient of the variable and '(*t*)' means the *t*-test score of this coeffcient. '*', '**', and '***' represent significance at the 10%, 5%, and 1% levels, respectively. 'Yes' means the model has controlled for the individual fixed effect. '−' means that the variable is not added to the specified model

production activities within a short distance are the major basis for container cargo generation. Similarly, *FT* also has a significant positive effect on *CT*. The coefficient of *RT* is significantly below 0, suggesting that *CT* may decrease during the economic structure transformation from secondary to tertiary industry in the hinterlands.

As *MN* and *PE* have experienced variations during the study period (Fig. 3), rolling regressions with a moving window of 15 yr were further developed based on Model 1 to show the dynamic influences of *MN* and *PE* on *CT*. Fig. 5 presents the coefficients of *MN* and *PE* at different time intervals. Specifically, *PE* and *MN* have significant positive explanatory power for *CT* in 1993–2011 and 2001–2019, respectively. Interestingly, their coefficients show opposite variation tendency during the study period. Specifically, coefficient of *PE* has increased first and then turned down with the dividing point in 1997–2011. Instead, the coefficient of *MN* has decreased first and then rebound and kept increasing with the dividing point in 1995–2009.

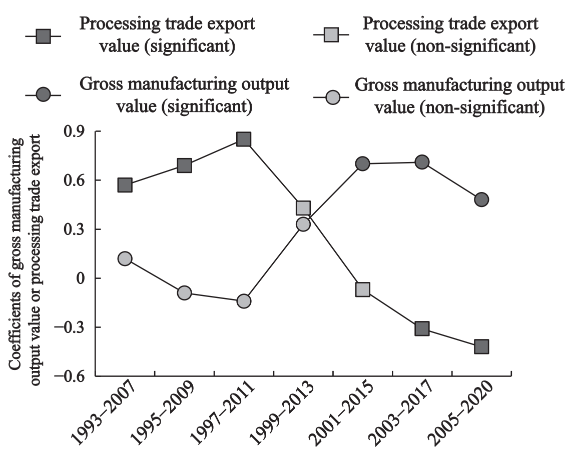

Fig. 5 Coefficients of gross manufacturing output value and processing trade export value in the time-phased panel model for the Pearl River Delta. 'significant' represents passing the test at a significance level of 10%

The significant difference of the tendency in coefficients of *PE* and *MN* can be explained by PRD's local context of an export-oriented economy. From the early 1990s to 2008 financial crisis, the positive contribution of manufacturing to container cargo was mainly rooted in its export-oriented component. Especially after Hong

Kong's return to China in 1997 and China's accession to the World Trade Organization (WTO) in 2001, mutual promotion and common growth in processing trade export values and container shipping peaked. Another result of China's accession to the WTO was to gradually transform traditional processing activities into higher value-added manufacturing. After 2008 financial crisis, manufacturing experienced a market transition from exports to domestic sales, and a new round of structural optimization, which have reduced the importance of low value-added and export-oriented processing in the local economy. Thus, there is a decline role of *PE* and an increase role of *MN* in contributing to *CT*. Note that there is a slight growth retardation or even decrease in the coefficients of *MN* in 2005–2019. This may be explained by the increase in the proportion of transshipment cargo in hub port and/or the increase in the added value per unit volume of manufacturing products.

3.2.2 Moderating effect of internal structural factors related to export-oriented economy

Regarding the manufacturing structural factor, the interaction terms of both $MN \times LB$ and $PE \times LB$ have significantly positive impacts on *CT* (Models 2 and 3) (Table 2). The higher the proportion of labor-intensive sector in manufacturing industry, the higher the port throughput generated per unit of manufacturing output. This result reflects the better adaptability of containerized traffic to labor-intensive products and/or raw materials. Interestingly, the coefficient magnitude of $PE \times LB$ is slightly larger than $MN \times LB$. After the reform and opening up, the PRD attracted a large number of labo-intensive processing enterprises in Hong Kong. Cargos of these enterprises were transported through Hong Kong to overseas, accounting for a significant share of *CT*.

For the structural factor of container ports, the interaction term of $PE \times TM$ has significantly positive impacts on *CT*, whereas the coefficient of $MN \times TM$ is not significant (Models 4 and 5). Therefore, the higher the degree of foreign capital agglomeration in the terminal enterprises, the greater the port throughput generated per unit of processing trade export value. Foreign business activities have simultaneously participated in manufacturing and terminal enterprises in PRD. Because at the initial stage, container ports in China faced disadvantages in shipping routes and professional knowledge, the government chose to invite foreign capital and operators. In 1986, the State Council issued *the Preferences for the Construction of Ports and Piers with Chinese and Foreign Joint Investment*. To a large extent, the initial development of ports in PRD has largely benefited from the northward spread of Hong Kong's port services (Wang, 1998). Thus, the path dependence of the involvement of foreign-invested container terminal enterprises still influences *CT* in PRD.

4 Discussion and Conclusions

4.1 Discussion

For developing countries, container ports and manufacturing are two factors that are functionally and spatially interconnected in economic globalization. The existing literature regarding the port-manufacturing relationship still presents inconsistent results. Our study enriches the debates on whether or not manufacturing has a significant impact on port development. Compared to the weakening port-city economy relationship in developed economies (Gripaios and Gripaios, 1995; Hall and Jacobs, 2012; Ducruet and Itoh, 2016; Li and Liu, 2022), results of this study lend support to the Asian hub port city model proposed by Lee et al. (2008) which highlights the positive role of manufacturing to port development. Specifically, the positive impact of hinterland's gross manufacturing output is universally remarkable throughout the PRD, implying a relatively independent source of goods for each port. This finding differs from the European cases where containers generated from vast inland area are concentrated in few gateway ports (Ducruet and Jeong, 2005) and inversely, comfirms the finding of Cullinane et al. (2005) and Notteboom and Rodrigue (2008) that it is more common for coastal manufacturing clusters in Asia to rely on adjacent container terminals to enter the global market. Our study also emphasizes that in the context of shipping organization modernization and hierarchical differentiation in a multi-port region, it is more reasonable to analyze the port-manufacturing relationship at the region scale instead of the city scale. As shown in the study carried by Ducruet and Itoh (2016), port-region scale shows good representativeness for the 'captive' part of the hinterland in the scenario where part of the port traffic comes from economic activities in surrounding cities.

Different conclusions in the port-manufacturing relationship between our studies and cases in developed countries can be explained by the local development context on the one hand (Ducruet and Itoh, 2016). Unlike developed countries commonly entering post-industrialization stage, China has undergone (and is still experiencing) rapid industrialization with an export-oriented economy. The port-manufacturing relationship may be deeply embedded in the export-oriented economy in which the local production resources are increasingly integrated into global production network through the interrelated multiple ports in the region (Wang et al., 2012; Wang and Slack, 2000). At the initial stage, port development served export processing activities to a large extent. And then the expansion of ports and manufacturing industries will benefit from the input of external capital, technology, and information, the implementation of open-door policies, and the rapid industrialization of port hinterlands. It means that cross-border investments in manufacturing and reorganization of the regional supply chains will lead to reconstruction of the port systems (Lee and Rodrigue, 2006; Liu et al., 2013). On the other hand, difference in the conclusions may also be attributed to the land corridor between ports and inland logistics nodes which has been better developed in Europe and North America (Monios and Wilmsmeier, 2012).

Although the positive impact of hinterland manufacturing on port development is found for each port, it is important to note that the function of different ports serving the export-oriented manufacturing may gradually differentiate in the development process (Wang et al., 2017). Currently, foreign trade containers are highly concentrated in hub ports. In the eastern PRD, the processing trade export value in Dongguan and Huizhou accounts for 22% and 10% of Guangdong Province, respectively, whereas both foreign trade container throughputs account for less than 1% in 2019. In line with the literature (Wang and Slack, 2000), a considerable number of foreign trade containers in Dongguan and Huizhou are first transported by trailers to Shenzhen and then shipped to foreign markets, which is also consistent with the hub port supply setting in the previous Huff model. In the western PRD, the manufacturing market is dominated by domestic trade, with foreign trade shipping services being self-sufficient. Typical representatives are Zhongshan and Foshan ports, where Hong Kong-funded terminal enterprises settled earlier. These inland ports are developing into an important link to coordinate the scale of maritime transport (Moeremans et al., 2023). Considering the lower cost of shipping than land transportation per unit container, as well as the traffic congestion faced by hub ports, we propose adjustments to the configuration of foreign trade routes to form a new trunk port in the eastern PRD relying on existing deep-water port resources. The new trunk port can improve the functional levels of port system by forming 'second-tier hubs' (Monios et al., 2019) and more effectively meet the diversified shipping needs of customers. In fact, both Dongguan and Zhuhai ports have committed to opening direct routes to Southeast Asia, West Asia, and other overseas markets (such as the Persian Gulf route for general cargo currently operated by Dongguan Port).

Regarding manufacturing structure and its spatial dynamics, a large number of labor-intensive enterprises have migrated from the PRD to the eastern, western, and northern areas of Guangdong Province and inland provinces after 2008 financial crisis. Our results on moderating effects suggest that manufacturing transfer and supply chains reshaped by migration may shift the logistics demand distribution. Therefore, the expansion of terminal loading and unloading services from the core area of the PRD to inland areas through port regionalization (Notteboom and Rodrigue, 2005) may be beneficial for organizing port logistics network to adapt to the new productivity layout and internal circulation, yielding coastal ports as the gateway between inland production bases and overseas markets. Industrial transfer also accelerated manufacturing upgrades in the PRD. The focus of manufacturing industries in coastal cities, such as Shenzhen, Dongguan, and Huizhou, has already shifted to technology-intensive fields. These technology-intensive industries will illicit new requirements for the timeliness and flexibility of shipping organizations to match the more complex logistics distribution under the flexible production mode. In addition to opening new foreign trade routes, appropriately increasing regional high-frequency and small-capacity liner services which integrate production, light processing, and logistics functions (Guo and Han, 2013) will be conducive to the two-way promotion of port containerization and manufacturing specialization in coastal areas. This proposed promotion is also consistent with existing evidence of the impact of regional economic structure on the scale and structure of port traffic (Ducruet and Itoh, 2016).

4.2 Conclusions

This study constructs an analytical framework to examine the relationship between container ports and hinterland manufacturing in the PRD with an export-oriented economy. By combining Huff and panel regression models, this study analyses the influence of hinterland manufacturing output and its foreign trade processing components on port container throughput across a long time period. The moderating effect of the internal structural factors related to an export-oriented economy in both manufacturing and terminal enterprises has been further verified. The conclusions are as follows.

(1) The Huff model effectively delineates the spatial pattern of hinterlands for hub ports, which can be adopted in future port-city economic relationship analysis to reduce the misestimation risk resulting from using the port city's administrative range as a statistical unit.

(2) The hinterland's gross manufacturing output value has universally positive impact on port throughput in the PRD during the period of 1993–2019. Rolling regression results show differences in the impact of different manufacturing components. Specifically, export-oriented processing has significantly positive impact on port throughput in 1993–2011; instead, the entire manufacturing industry has significantly positive impact on port throughput in 2001–2019.

(3) Two internal structural factors, labor-intensive sectors and foreign-funded terminals, have positively moderated the direct influence of hinterland manufacturing on port throughput. The magnitude of moderating effect is slightly higher for the processing trade export value.

It is recognized that the present study also has some limitations. First, other environmental factors that may affect the relationship between manufacturing and port development in PRD should be controlled in the future research. Second, given the importance of local context in understanding port-city economic relationship, factors related to government policies and their evolutions regarding local context should also be further tested. Given the increasing uncertainty in economic globalization, the relationship between manufacturing and port development deserves long-term tracing and researching in the future.

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