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PORTS AND ECONOMIC DEVELOPMENT OF PORT CITIES IN PEARL RIVER DELTA BASED ON PANEL VECTOR AUTOREGRESSIVE MODEL

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Abstract. *As an essential and pivotal link to economic growth, especially in coastal areas, port is closely related to the regional economy. Unlike previous studies in the port-city interaction literature, this paper establishes a panel vector autoregressive (PVAR) model to empirically examine the dynamic relationships between port development and the port city economy. This study is conducted for nine port cities in Pearl River Delta from 2005 to 2019 and the results reveal that in Pearl River Delta, a mutually reinforcing relationship exists between port and the port-city economy, which features unique regional economic traits. First, due to the high degree of regionalization of the Pearl River Delta port cluster, the self-promotion effects of the port logistics, port infrastructure, and the economic growth of port cities are much greater than the mutual interaction effects among those variables. Second, the port infrastructure optimization may lead to the negative impact of port infrastructure on the development of port logistics. This study provides a new dynamic perspective for port-city interaction research.*

Keywords: Regional economy, Port city development, PVAR model

1. **Introduction.** Ports serve as comprehensive transportation hubs as well as strategic resources for the economic and social development of the hinterland city [1]. Reversely, the economic scale and economic development vitality of the hinterland cities are the effective supports for the ports [2], being the economic environment contributor to the ports efficiency evaluation [3]. The port layout plan of Guangdong Province (2021-2035) puts forward the guidance of building world-class ports in China, and a "one core and two poles" development pattern with the Pearl River Delta port cluster as the "core". Pearl River Delta is perfectly located in the core of the Guangdong-Hong Kong-Macao Greater Bay Area and is not only a typical densely distributed port cluster, but also the most developed and concentrated area of economy, industry, and trade. Therefore, a thorough discussion of the relationship between port and the port city economy helps to provide insightful implications for a development path to the "world-class port" and giving full play to the radiation of the Greater Bay Area to drive the economic growth of the surrounding hinterland.

Scholars have made unremitting exploration on the port-city specific relationship pattern, mutual influence mechanism and key factors. The research content and paradigm have been continuously enriched recently. For instance, Song and Geenhuizen [1] took four port clusters in China as an example to prove that the investment in port infrastructure can promote regional economic growth; Heijman et al. [4] verified the mutual enhancing

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effects between port and regional economy in Rotterdam; Guo et al. [2] studied the influence of the port size and port internal structure on the port-city relationship; Using the container throughput, hinterland GDP and the number of employment as research variables, Yang et al. [5] found that the role of port in the development of its hinterland city economy has obvious stage; Lu et al. [6] put forward the coordinated port city development strategy on the basis of the model of the synergy degree of provincial ports and cities along the Belt and Road.

Furthermore, as for the interaction mechanism, methodologically, most of the research focuses on the dynamic interaction using time-series techniques such as the vector autoregressive model (VAR), impulse response function, and Granger causality test [2,5]. However, the time-series techniques can only be applied to one particular port, while it should help policymakers to identify a more general pattern in a certain region or country in a horizontal direction by using panel data [1,4]. Nevertheless, panel data analysis techniques do not contain interaction dynamics over time. Moreover, in the few studies considering both horizontal panel data and time-series dynamics, the cross-sectional dependence which will reduce the effectiveness of coefficients estimation is barely considered [6]. With the help of the second-generation panel method which was progressed lately and able to deal with cross-sectional dependence, Cong et al. formulated the port-city interaction as a first-order-lag dynamic panel model [7]. However, this resolution was not perfect for it only treated the dynamic port-city interaction as one way instead of reciprocal, and analyzed the dynamic effects for just one time period instead of multiple time periods. Additionally, although the studies on port and the port city economy are relatively rich, similar research specifically focusing on the Pearl River Delta port cluster is rare.

In view of this, the paper conducts an empirical study on panel data in Pearl River Delta by establishing a panel vector autoregressive (PVAR) model, which inherits the advantages of the VAR model, and also integrates the second-generation panel model techniques as well. In this way, a more thorough port city interaction analysis can be provided.

2. The PVAR Model of Port and Port City Economy.

The panel vector autoregressive (PVAR) model is developed by Love and Zicchino [8] and improved by Lian [9]. Evolved from the VAR model, the PVAR approach treats all variables as endogenous, so that each PVAR variable relies not only on its historical realization but also on other variables, revealing a real interdependence among system variables [10]. Besides, like traditional panel data models, PVAR allows to account for unobserved heterogeneity of individual port cities via the introduction of fixed effects and unobserved common macroeconomic effects via the introduction of time-fixed effects for different time periods [10]. Therefore, compared to traditional time series or panel models, PVAR is a more practical instrument for exploring the mutual impact of the port and the port city economy.

2.1. Index selection.

Referred to previous studies, the port logistics is most repeatedly used to analyze the interaction mechanism between port and the port city economy [2,5]. Generally the port logistics can be expressed by the two indicators: cargo throughput and container throughput. The container throughput has become the main indicator reflecting the port development, especially with the popularization of container technology in the Pearl River Delta port cluster, whereas the cargo throughput is used to describe the traditional port development mainly with dry bulk cargo [11]. Therefore, the container throughput is selected to characterize port logistics here. Besides, the number of berths is selected to represent port infrastructure construction [1], and the gross domestic product (GDP) is referred to as the representative of the port city economy [4].

2.2. **Data selection.** The research scope of this paper covers nine port cities in Pearl River Delta, which consist of Guangzhou, Foshan, Shenzhen, Zhuhai, Dongguan, Huizhou, Jiangmen, Zhongshan, and Zhaoqing. The data mainly comes from the Port Statistical Yearbook, the Guangdong Provincial Statistical Yearbook and the Urban Statistical Yearbook. Annual data on the container throughput, number of berths and urban GDP from 2005 to 2019 have been collected. Logarithmic processing is performed on the three variables, so as to reduce heteroscedasticity, and increase stationarity.

2.3. **Series stationarity test.** Before proceeding with the PVAR framework, unit root tests are conducted to examine the data series stationarity. There are two generations of unit root tests. While the first-generation of unit root tests deals with units independence, the second-generation acknowledges the cross-sectional dependence [12]. In order to ensure the test results convincing, the first-generation unit root tests of Levin-Lin-Chu (LLC) and Breitung as well as the second-generation of Fisher Augmented Dickey-Fuller (Fisher-ADF) and Fisher Phillips-Perron (Fisher-PP) are selected. For each data sequence, if the hypothesis of the existence of a unit root is rejected in both first-generation and second-generation unit root tests, then the sequence is considered stationary, and vice versa [10]. The unit root test results are reported in Table 1.

Table 1. Stationarity test of model variables

Variables	LLC	Breitung	Fisher-ADF	Fisher-PP
ln_containerput	-2.6322^{***}	-2.1685^{**}	14.4780	5.5447^{***}
	(0.0042)	(0.0151)	(0.6974)	(0.0000)
ln_berthnum	2.1091	-1.7310^{**}	2.8603^{***}	26.3419^{***}
	(0.9825)	(0.0417)	(0.0021)	(0.0000)
ln_gdp	1.8729	-0.7297	-0.5379	30.6944^{***}
	(0.9695)	(0.2328)	(0.7047)	(0.0000)
dln_gdp	-2.6668^{***}	-3.4190^{***}	1.3401^{*}	1.8594^{**}
	(0.0038)	(0.0003)	(0.0901)	(0.0315)

Note: The numbers in brackets are P values; "*", "**", "***" represent the rejection of the null hypothesis at the significant level of 10%, 5%, and 1%, respectively.

Table 1 shows that, the logarithmic container throughput (ln_containerput) is significantly stationary in LLC, Breitung and Fisher-PP tests, and the logarithmic number of berths (ln_berthnum) is significantly stationary in Breitung, Fisher-ADF and Fisher-PP tests. However, since the unit root hypothesis of the logarithmic GDP (ln_gdp) can only be significantly rejected in Fisher-PP test, the difference sequence of the logarithmic GDP (dln_gdp) is selected for it is significantly stationary in all unit root tests.

2.4. **PVAR model construction.** The proposed PVAR model is given by

$$y_{it} = \alpha_0 + \sum_{j=1}^{p} \beta_j y_{it-j} + f_i + d_t + \varepsilon_{it} \tag{1}$$

where y_{it} is a vector of the endogenous series ($\text{ln\_containerput}_{it}$, ln_berthnum_{it}, dln_gdp_{it}), describing the index set of the logarithmic container throughput, number of berths and the first difference of logarithmic GDP (GDP growth). i refers to port city and t refers to year. α_0 is the intercept vector. y_{it-j} represents the jth lagging items of the endogenous series ($\text{ln\_containerput}_{it-j}$, $\text{ln\_berthnum}_{it-j}$, dln_gdp_{it-j}), and j is the lag length, $j \in (1, \ldots, p)$ with p the optimal lag order of the PVAR model. β_j represents the regression coefficient matrix of the jth lagging items. The individual fixed effect is indicated by f_i and the fixed time effect is d_t. ε_{it} denotes the residual vector.

In order to construct the PVAR model, Akaike Information Criterion (AIC), Schwarz Information Criterion (SIC) and Hannan-Quinn Information Criterion (HQIC) are used to determine the optimal model lag order p. The test results reported in Table 2 suggest that AIC, SIC, and HQIC all have the optimal value at lagging 1 step.

TABLE 2. Selection of lag order of PVAR model

Lag	AIC	SIC	HQIC
1	-4.9105^*	-4.0606^*	-4.5654^*
2	-4.3798	-3.2623	-3.9267
3	-3.8348	-2.4192	-3.2620
4	-3.1506	-1.4008	-2.4450

Note: * signals the optimal value.

A lag 1-order PVAR model can be written in the following form:

$$y_{it} = \alpha_0 + \beta_1 y_{it-1} + f_i + d_t + \varepsilon_{it} \tag{2}$$

Substituting the indicator variables, the PVAR matrix form can be written as:

$$\begin{pmatrix} \text{ln\_containerput}_{it} \\ \text{ln\_berthnum}_{it} \\ \text{dln\_gdp}_{it} \end{pmatrix} = \begin{pmatrix} \alpha_{01} \\ \alpha_{02} \\ \alpha_{03} \end{pmatrix} + \begin{pmatrix} \beta_{11} & \beta_{12} & \beta_{13} \\ \beta_{21} & \beta_{22} & \beta_{23} \\ \beta_{31} & \beta_{32} & \beta_{33} \end{pmatrix} \begin{pmatrix} \text{ln\_containerput}_{it-1} \\ \text{ln\_berthnum}_{it-1} \\ \text{dln\_gdp}_{it-1} \end{pmatrix} + \begin{pmatrix} f_1 \\ f_2 \\ f_3 \end{pmatrix} + d_t + \begin{pmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \\ \varepsilon_{3t} \end{pmatrix} \tag{3}$$

In PVAR model estimation, the PVAR2 package in STATA15 is adopted. The "Helmert procedure" [8] is used to control individual fixed effects, together with a more effective panel generalized moment estimation method (GMM) to determine the parameters [10]. Besides, due to the difficulty of interpreting the parameter estimates in PVAR model [5], the panel impulse response functions (IRFs) are used to evaluate the impact of the orthogonal shocks from one variable to another while keeping all other variables invariant. Simultaneously, the variance decomposition is conducted to show the relative contribution of system variables in percentage to the variance of each variable, and to observe the dynamic change of the relative contribution in percentage over time.

3. Empirical Results Analysis.

3.1. PVAR estimation results. The GMM estimation results of the constructed PVAR model reported in Table 3 show that there are four statistically significant coefficients. In particular, the coefficients of the first lags of the container throughput, the number of berths, and the GDP growth to their current level are all statistically significant at the 1% level. Additionally, in column 2, the first lag of GDP growth has a positive impact at the 10% level of significance on the current number of berths, which indicates that the increasing GDP growth will prompt the port infrastructure construction. This result is in accordance with the previous studies that the port city economy is strongly correlated with the port infrastructure [2,5].

TABLE 3. GMM estimation results

	$ln\_containerput_{it}$	$ln\_berthnum_{it}$	dln_gdp_{it}
$ln\_containerput_{it-1}$	0.845^{***}	-0.042	-0.018
	(0.000)	(0.232)	(0.309)
$ln\_berthnum_{it-1}$	0.204	0.664^{***}	0.079
	(0.518)	(0.006)	(0.334)
dln_gdp_{it-1}	0.036	0.339^{*}	0.594^{***}
	(0.938)	(0.055)	(0.000)

Note: The numbers in brackets are P values; "*", "**", "***" represent the rejection of the null hypothesis at the significant level of 10%, 5%, and 1%, respectively.

3.2. **Panel impulse response analysis.** Figures 1, 2, and 3 depict the panel impulse response functions (IRFs) of the container throughput, number of berths and GDP growth. In each figure, the horizontal axis represents the number of response periods of 0-6, and the vertical axis represents the response variable change. The solid line describes how a response variable reacts to the shock. The dashed lines on the upper and lower sides of the solid line represent the upper and lower boundaries of the 95% confidence interval, respectively.

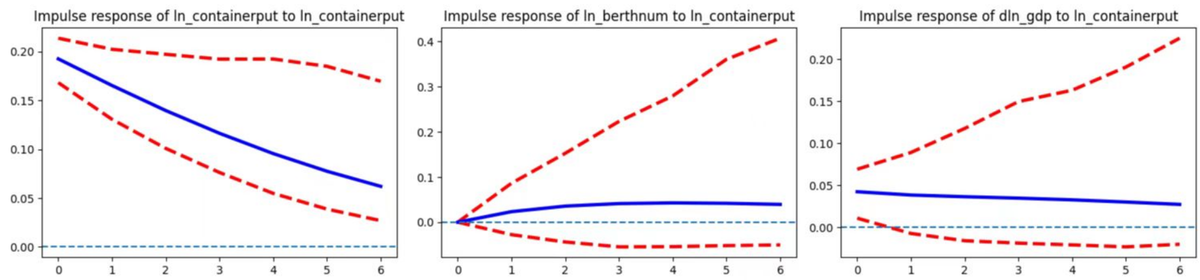

FIGURE 1. Impulse response to ln_containerput

Figure 1 illustrates the reaction of the container throughput, number of berths, and GDP growth to one standard deviation shock in the container throughput.

First, the effect of one standard deviation shock in the container throughput on itself is instantaneously positive, then gradually decreases, but remains positive in the 6-year periods, indicating that the growth of the container throughput contributes positively to itself, and the positive effect lasts for several years.

Second, the response of the number of berths to one standard deviation shock in the container throughput is zero at year 0, then gradually increases and remains positive to a limited extent. It seems that the contribution of the container throughput to the number of berths is positive but weak, which is in line with the past research results that the growth of port logistics stimulates the construction of port infrastructure [4,11].

Third, the reaction of the GDP growth to one standard deviation shock in the container throughput is instantly positive, then declines a bit over the 6 years, suggesting that the growth of port logistics will also enhance the GDP growth of the hinterland city.

The results in Figure 2 show the response of the container throughput, number of berths, and GDP growth to one standard deviation shock in the number of berths.

First, the impact of one standard deviation shock in the number of berths on the container throughput is positive at year 0, then the impact drops slowly to zero after one year period, and then keeps declining from year 2 to year 6. The tendency shows

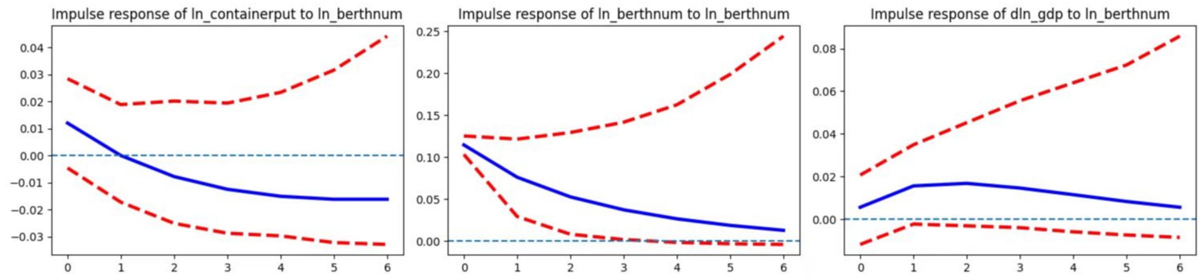

FIGURE 2. Impulse response to ln_berthnum

that the development of port infrastructure will assist port logistics at the beginning, but curb it later on. The later containment effect may be explained that after several years of rapid development, the port infrastructure in the Pearl River Delta has led to repeated construction and caused vicious competition among the ports. Therefore, to keep building port infrastructure continuously is not able to improve the port logistics any more.

Second, the effect of one standard deviation shock in the number of berths on itself is positive, and the positive effect lasts for several years.

Third, the response of the GDP growth to one standard deviation shock in the number of berths is slightly above zero at the beginning, then rises a bit in the first two years, but decreases gradually afterwards though remains positive, suggesting that the increase of the number of berths encourages the GDP growth. which agrees with the idea of Song and Geenhuizen [1] and Heijman et al. [4] that the port infrastructure enhances the port city economy.

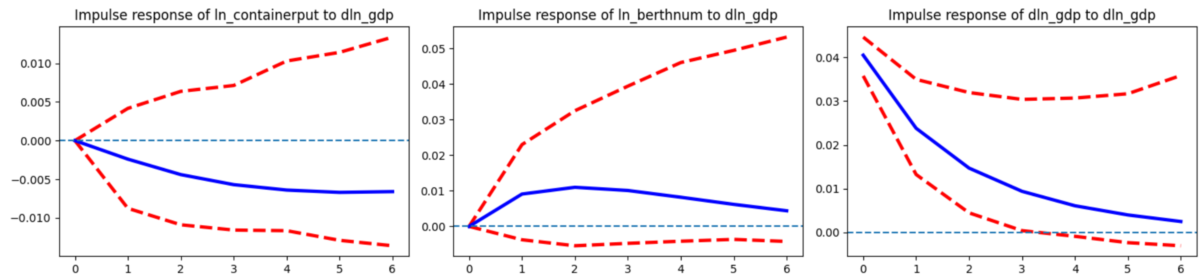

FIGURE 3. Impulse response to dln_gdp

Figure 3 shows the reaction of the container throughput, the number of berths, and the GDP growth to one standard deviation shock in the GDP growth.

First the impact of one standard deviation shock in the GDP growth on the container throughput is 0 at year 0, then the impact drops to negative thereafter, indicating that the increase of the GDP growth will suppress the port logistics. With reference to the empirical evidence in Table 3 and Figure 2, it may be explained that the increase of GDP growth will advance the port infrastructure construction, which in turn will curb the port logistics.

Second, the response of the number of berths to one standard deviation shock in the GDP growth is zero at the beginning, then increases a bit in the first two years, but decreases gradually afterwards though keeps positive, suggesting that the increase of the GDP growth encourages the port infrastructure. It confirms the idea of Guo et al. [2], and agrees with the empirical evidence in Table 3.

Third, the effect of one standard deviation shock in the GDP growth on itself is positive, and it lasts for several years.

3.3. **Analysis of variance decomposition.** The variance decomposition is conducted over 30 years, and the results are reported in Table 4.

TABLE 4. Variance decomposition results

Variance decomposition variable	Year periods	Impact explanatory variable		
		dln_gdp_{it}	$\text{ln\_containerput}_{it}$	ln_berthnum_{it}
	10	0.070	0.848	0.082
$\text{ln\_containerput}_{it}$	20	0.073	0.833	0.093
	30	0.073	0.833	0.094
	10	0.038	0.064	0.898
ln_berthnum_{it}	20	0.037	0.081	0.882
	30	0.038	0.081	0.881
	10	0.778	0.088	0.135
dln_gdp_{it}	20	0.759	0.108	0.133
	30	0.758	0.109	0.133

In Table 4, the variations in the row variables are explained by the changes of column variables in percentage.

In terms of the container throughput, the container throughput itself contributes more than 83% over time; whereas the GDP growth interprets approximately 7.3%, and the number of berths explains less than 9.4% of the variations of the container throughput. The results demonstrate that the container transportation is more affected by itself than by the hinterland city economy and the port infrastructure.

Referring to the number of berths, the changes in the number of berths are more dependent on the fluctuations of its own, with a proportion of more than 88% in 30 years; while the GDP growth variations explain less than 4%, and the container throughput changes explain about 8%. It may suggest that the influences of both the hinterland city economy and the port logistics on the port infrastructure are limited.

For the GDP growth, the explanatory proportions of the container throughput are from 8.8% to 10.9% from 10 to 30 years; the proportions of the number of berths are approximately 13% over time, and the proportions of the GDP growth itself are more than 75%. This shows that the port logistics and the port infrastructure play a certain role in the GDP growth, and the GDP growth has a self-reinforcing mechanism as well.

Additionally, the results as a whole suggest that the variance contribution proportions do not change much from year 20 to year 30, indicating that the dynamic relationship among the container throughput, the number of berths, and the GDP growth in the Pearl River Delta reaches equilibrium in 20-30 years.

4. **Conclusions.** By means of the PVAR model, based on the panel data of nine port cities in the Pearl River Delta from 2005 to 2019, this paper has empirically analyzed the interaction among the port logistics, port infrastructure and economic growth of port city. The research conclusions provide policy enlightenment for the Pearl Rive Delta to continue to improve the level of port operation, strengthen the integration of regional port resources, optimize the connectivity between ports and hinterland transportation infrastructure, so as to achieve a better port-city coordinated development. The conclusions are drawn as the following.

First of all, consistent with the previous studies, the empirical results show that the port infrastructure construction and the economic growth of the port city mutually promote each other; and that the port logistics encourages the economic growth of the port city.

On the other hand, the empirical evidences also indicate unique characteristics of the port-city interaction in the Pearl River Delta.

First, the port logistics, port infrastructure, and the economic growth of the port city all have positive impacts on their own. These self-promotion effects are much greater than the mutual impacts among the three variables. It is most likely to be attributed to the port regionalization development. Literally, Outline of the Reform and Development Plan for the Pearl River Delta (2008-2020) has put forward the development strategy of regional integration of Guangdong Hong Kong and Macao, leading to a high regional integration level in the Pearl River Delta. Thus the port development is related rather to the overall regional economy than to the hinterland's.

Second, the progress of the port infrastructure will hinder the development of port logistics, and the economic growth of the port city also has a negative effect on the port logistics. This is most likely to be attributed to the port infrastructure optimization. Literally, both repeated construction of the port infrastructure and vicious competition among ports require port infrastructure optimization. Further, since the container terminal of Nansha port was built in 2006, the container technology popularization has brought about the transformation of traditional terminals into container terminals. As a result, the quantity of port infrastructure is generally reduced, yet the overall port logistics is growing for a more reasonably and scientifically planned port infrastructure.

The research of this paper has the following limitation: the PVAR model treats the Pearl River Delta as a whole, so that the individual port city heterogeneity analysis is neglected. The authors will further study the limitation in the future.

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