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IMPACT OF PORT-CITY COORDINATION UPON HINTERLAND ECONOMY IN PEARL RIVER DELTA

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Abstract. *Coordinated development of ports and hinterland cities functions as the foothold of the sustainable development of port cities. By establishing the synergy degree model of port-city complex system, this paper analyzes the synergy degrees of 9 port cities in Pearl River Delta. Based on the calculation of synergy degree, a panel data measurement model has been built to study the impact of the port-city synergy degree on hinterland economic growth. By comprehensively using both of the synergy model and the panel measurement model, avoiding the single perspective defect in empirical methods, the analysis of the impact of port-city coordination upon hinterland economy has become more complete and thorough. Results have shown that in the Pearl River Delta, port-city coordination exerts quite a significant role in promoting regional economic growth. Besides, for different ports, the effect of port-city coordination on regional economy varies.*
Keywords: Port-city coordination, Composite system synergy degree model, Panel data model, Pearl River Delta

1. **Introduction.** By integrating capital, technology, logistics and information, port serves as the gateway and economic growth pole of hinterland cities, of which economic scale and economic vitality are the effective support for port development. Ports and cities function as sub-systems, sharing the same spatial resources with close economic ties. In order to achieve sustainable port-city coordinated development, scholars have conducted in-depth explorations on the relationship between ports and cities. On the one hand, some scholars explore the role of the port in promoting the hinterland economy. Bottasso et al. take the European ports as a sample, and analyze the impact of port throughput on employment and regional economic development [1,2]. Song and Geenhuizen take four major port regions in China as examples and confirm that port infrastructure investment can promote regional economic growth [3]. On the other hand, some scholars investigate the supporting role of the hinterland economy on the port. Guo et al. reveal the dynamic effects of hinterland on ports through empirical research [4]. Li et al. explore the specific impact of the three major industries on the port [5]. Yet at present, scholars focus more on the port-city coordination based on the Synergetics theory. Xiao and Lam put forward the systematic theory of the sustainable development of ports and cities, taking Singapore as an example [6]. Fan et al. empirically test the effect of port-city coordination on urban economic development [7]. Berghe et al. take Amsterdam and Ghent ports as examples to study the coupling mechanism of port and urban development [8]. Lu et al. utilize the panel data of port-city synergy degrees to conduct an empirical research and propose corresponding port-city development strategies [9]. Xing constructs a DID model to estimate

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the impact of the Belt and Road initiatives on local urbanization level, and port-hinterland synergy [10]. Scholars have discovered that port-city coordination has become a foothold for improving the comprehensive capabilities of port cities and materializing sustainable economic development. Although numerous studies have successively adopted empirical methods to assess port-city coordination, quantitative studies specifically for the impact of the port-city synergy degree on regional economy are rarely seen. Besides, current literature on port-city coordination focuses on well-known ports and large cities, yet studies that specifically focus on the Pearl River Delta are limited. However, the Pearl River Delta is not only a typical densely distributed port cluster, but also one of the most developed and concentrated areas of economy, industry and trade. Studying how port-hinterland coordinated development influences urban economic growth is likely to help formulate a coordinated development strategy for the Pearl River Delta, and for the Guangdong-Hong Kong-Macao Greater Bay Area as well. Therefore, this paper takes the Pearl River Delta as an example, sets out to examine the coordinated port-city development and studies directly the impact of port-city synergy degree on the urban economy.

This paper is arranged as the following: the first part is the introduction; the second part is the synergy degree model of the port-city complex system; the third part is the panel measurement model of the effects of the port-city synergy degree on the hinterland economy; the fourth part is the conclusion.

2. **Port-City Composite System Synergy Degree Model.** Based on Synergetics theory, with reference to the overall synergy degree model proposed by Meng and Han [11], this paper constructs the synergy degree model of the port-city complex system.

Suppose the port-city complex system is composed of the port subsystem S_1, and the hinterland economic subsystem S_2. For subsystems S_i, $i = [1, 2]$, the order parameters in the evolution process is $e_i = (e_{i1}, e_{i2}, \ldots, e_{in})$, $n \geq 1$. Each certain order parameter e_{ij} has m samples, and satisfies $U_{ij} \leq e_{ij} \leq T_{ij}$. The order degree of a subsystem is calculated by Formula (1):

$$\mu(e_{ij}) = \left\{ \begin{array}{ll} \dfrac{e_{ij} - U_{ij}}{T_{ij} - U_{ij}}, & j \in (1, k_1) \\ \dfrac{T_{ij} - e_{ij}}{T_{ij} - U_{ij}}, & j \in (k_1 + 1, n) \end{array} \right\} \tag{1}$$

Obviously, $\mu(e_{ij}) \in [0, 1]$, and the greater its value, the greater the contribution of e_{ij} is to the order of the system.

$$\mu_i = \sum_{j=1}^{n} \omega_j \mu(e_{ij}), \quad \omega_j \geq 0 \wedge \sum_{j=1}^{n} \omega_j = 1 \tag{2}$$

The total contribution of all parameters e_{ij} to subsystem i is calculated by Formula (2). Determined by the entropy weighting method, ω_j is the weight coefficient for e_{ij}. Besides, Formulae (3), (4) and (5) introduce the synergy degree F which reflects the overall degree of coordinated development of the two subsystems. F is between $[0, 1]$, and can be divided into 10 levels: extremely uncoordinated (0.0-0.1), seriously uncoordinated (0.1-0.2), moderately uncoordinated (0.2-0.3), mildly uncoordinated (0.3-0.4), on the verge of uncoordinated (0.4-0.5), reluctantly coordinated (0.5-0.6), primarily coordinated (0.6-0.7), intermediately coordinated (0.7-0.8), well coordinated (0.8-0.9), and excellently coordinated (0.9-1) [11].

$$C = \sqrt{\frac{\prod_{i=1}^{2} \mu_i(e_i)}{\left(\sum_{i=1}^{2} \mu_i(e_i)/2\right)^2}} \tag{3}$$

$$D = \left(\sum_{i=1}^{2} \mu(e_i)\right) \Big/ 2 \tag{4}$$

$$F = \sqrt{C \times D} \tag{5}$$

In calculating the port-city synergy degrees in the Pearl River Delta, according to the existing literature [7,9,10], for the port subsystem, cargo throughput, container throughput, port berth length, the number of berths, and the number of berths over 10,000 tons are chosen as the order parameters. And for the city subsystem, the order parameters are GDP (Gross Domestic Product), Import&Export. The calculated port-city synergy degrees in Pearl River Delta are shown in Table 1.

TABLE 1. The port-city synergy degrees in Pearl River Delta (by year)

Year	Guangzhou	Foshan	Shenzhen	Zhuhai	Dongguan	Jiangmen	Huizhou	Zhongshan	Zhaoqing
2005	0.5128	0.3153	0.5284	0.3685	0.3372	0.3567	0.4121	0.3215	0.2455
2006	0.5860	0.4051	0.6124	0.4158	0.3599	0.4805	0.4798	0.3647	0.3022
2007	0.6382	0.4217	0.6957	0.5044	0.3814	0.5184	0.5412	0.3822	0.3434
2008	0.6470	0.4256	0.7040	0.5362	0.4430	0.5384	0.6236	0.3734	0.3732
2009	0.6666	0.4289	0.6995	0.5306	0.4871	0.5261	0.6738	0.4164	0.3921
2010	0.7434	0.4711	0.7819	0.6148	0.5629	0.5887	0.7527	0.4828	0.4534
2011	0.7704	0.4768	0.8026	0.6521	0.5836	0.6219	0.7818	0.4974	0.5117
2012	0.7828	0.4554	0.8312	0.6586	0.6935	0.7105	0.8311	0.4907	0.5379
2013	0.7979	0.4770	0.8465	0.7690	0.7598	0.7331	0.8709	0.5325	0.5555
2014	0.8285	0.4932	0.8784	0.8126	0.8252	0.7853	0.8903	0.5585	0.5052
2015	0.8686	0.5021	0.8472	0.8248	0.8653	0.7957	0.8968	0.5574	0.6207
2016	0.8917	0.5165	0.8665	0.8528	0.8971	0.8090	0.8985	0.5818	0.6269
2017	0.9458	0.5540	0.9157	0.9355	0.9457	0.8317	0.9319	0.5701	0.6429
2018	0.9901	0.5752	0.9416	0.9633	0.9579	0.8264	0.9807	0.5988	0.6398
2019	0.9665	0.5917	0.9555	0.9866	0.9991	0.8626	0.9563	0.6176	0.6445

Note: The order parameters indexes used to calculate the port-city synergy degrees are obtained from the China Port Statistical Yearbook. To make the calculation results more accurate, the individual abnormal data were smoothed. For example, from 2005 to 2007, the number of berths above 10,000 tons in Zhaoqing, reflected in the China Port Statistical Yearbook are respectively 0, 11, 0, then after smoothing, become 0, 0, 0.

Table 1 shows that the port-city synergy degrees in the Pearl River Delta have all increased during the 15-year period, which is consistent with the unified planning and deployment strategy in the Pearl River Delta. Yet in terms of synergy degree, the results achieved in the end are quite different for different ports. In sum, the synergy degrees of inland river port cities (Foshan, Zhongshan and Zhaoqing) are lower than those of other coastal ones, which indicates that in the Pearl River Delta, the coastal port cities achieve greater coordination development than inland river port cities do.

3. **Empirical Analysis of Panel Measurement Model.** A complete set of universal port model theory has been built based on the Anyport-type model coined by British geographer Bird [12]. According to the Port Location Theory and the Anyport-type model idea, there is a strong interaction between port development and hinterland economic growth; thus, this paper constructs panel data models to empirically analyze the influence of the port-city synergy degree on the hinterland economy.

3.1. **Indicators and data selection.** With reference to the research of Lu et al. [9], Xiong and Xu [13], this paper uses GDP to reflect the economic growth level; the synergy degree of port-city system indicates the level of port-city coordination; the total fixed asset investment of the whole society represents capital investment; the number of employees at

the end of the year represents labor input; and the volume of freight turnover to represent the level of logistics and transportation.

For data selection, this paper adopts the panel data of nine major port cities in the Pearl River Delta. All data related to prices are deflated based on the 2005 Consumer Price Index (CPI). In addition, in order to eliminate the influence of data units, reducing heteroscedasticity, all indicators but the synergy degree are processed in logarithms. For the synergy degree, logarithmic processing tends to distort its original reference.

3.2. **Data verification.** In order to avoid spurious regression, the variable series needs to pass unit root test prior to model estimation. In order to ensure the test results convincing, the common unit root tests of Levin-lin-chu (LLC), and Breitung, as well as the individual unit root tests of Fisher Augmented Dickey-Fuller (Fisher-ADF), and Fisher Phillips-Perron (Fisher-PP) are selected. For each variable series, if the hypothesis of the existence of unit root is rejected in both common and individual unit root tests, then the sequence is considered stationary. The unit root test results are shown in Table 2.

Table 2. Unit root test of model variables

Variables	Meaning	LLC	Breitung	Fisher-ADF	Fisher-PP
$\ln_GDP_{it}$	GDP	-0.5895	-0.2238	6.7099^{***}	13.0362^{***}
		(0.2778)	(0.4115)	(0.0000)	(0.0000)
$port_city_coor_{it}$	Port&city coordination	-0.0923	-2.6415^{***}	6.6504^{***}	6.9292^{***}
		(0.4623)	(0.0041)	(0.0000)	(0.0000)
$\ln_fasset_investment_{it}$	Fixed asset investment	-4.2361^{***}	0.8259	-1.3426	1.3021^{*}
		(0.0000)	(0.7956)	(0.9103)	(0.0964)
$\ln_labor_{it}$	Number of employees	-0.5231	-2.0720^{**}	0.8680	21.6784^{***}
		(0.3005)	(0.0191)	(0.1927)	(0.0000)
$\ln_freight_turnover_{it}$	Freight turnover	-2.7517^{***}	-2.3391^{***}	18.0431^{***}	7.8756^{***}
		(0.0000)	(0.0097)	(0.0000)	(0.0000)
$dln_fasset_investment_{it}$	Fixed asset investment growth	-5.8606^{***}	-0.8326	0.2906	29.5713^{***}
		(0.0000)	(0.2025)	(0.3857)	(0.0000)

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 2 shows that, given 5% significance level, the logarithmic GDP ($\ln_GDP_{it}$), the port-city synergy degree ($port_city_coor_{it}$), the logarithmic number of employees ($\ln_labor_{it}$), the logarithmic freight turnover ($\ln_freight_turnover_{it}$) are stationary. Whereas since the unit root hypothesis of the logarithmic fixed asset investment ($\ln_fasset_investment_{it}$) can only be rejected at 10% level, the logarithmic difference sequence of the fixed asset investment ($dln_fasset_investment_{it}$) is tested and finally selected for the panel model.

3.3. **Model setting and testing.** This paper constructs the following panel data models:

$$\begin{aligned}\ln_GDP_{it} = {} & \alpha_0 + \alpha_1 port_city_coor_{it} + \alpha_2 dln_fasset_investment_{it} + \alpha_3 \ln_labor_{it} \\ & + \alpha_4 \ln_freight_turnover_{it} + \varepsilon_{it} \quad (i = 1, 2, \ldots, 9,\ t = 1, 2, \ldots, 15)\end{aligned} \tag{6}$$

$$\begin{aligned}\ln_GDP_{it} = {} & \beta_0 + \beta_1 port_city_coor_{it-1} + \beta_2 dln_fasset_investment_{it} + \beta_3 \ln_labor_{it} \\ & + \beta_4 \ln_freight_turnover_{it} + \varepsilon_{it} \quad (i = 1, 2, \ldots, 9,\ t = 1, 2, \ldots, 15)\end{aligned} \tag{7}$$

In Formulae (6) and (7), the subsequent i refers to port cities and t refers to year. α_0 is the intercept for Model (6), and β_0 is the intercept for Model (7). Model (6) is used to reveal the impact of the current port-city synergy degree ($port_city_coor_{it}$) on the GDP with the coefficient α_1. The $dln_fasset_investment_{it}$, the $\ln_labor_{it}$, and the $\ln_freight_turnover_{it}$ are

used as the controlled variables, with α_2, α_3 and α_4 as the coefficients, respectively. Model (7) is used to discover the delaying effects of port-city synergy degree on the GDP with the first lag of port-city synergy degree ($\text{port_city_coor}_{it-1}$) as the explanatory variable with the coefficient β_1. In Model (7), the controlled variables are consistent with in Model (6), with β_2, β_3 and β_4 as the respective coefficients. ε_{it} denotes the stochastic residual. Model (7) can also be used as a robustness verification of Model (6).

According to panel model setting tests results in Table 3, Models (6) and (7) should adopt the individual fixed-effect model. Although there is no obvious serial correlation, cross-sectional correlation and cross-sectional heteroscedasticity are detected.

Table 3. Panel model setting test

Types of test statistics	Model (6)	Model (7)	Types of test statistics	Model (6)	Model (7)
F_1	300.04*** (0.0000)	34.57*** (0.0000)	F_3	1.147 (0.3154)	0.619 (0.4540)
Hausman test	12.61** (0.0273)	11.07** (0.050)	X_1	57.604** (0.0126)	58.567** (0.0101)
F_2	1.19 (0.2959)	1.28 (0.2298)	X_2	911.82*** (0.000)	906.02*** (0.000)

Note: F_1 is the statistics to check the individual fixed effects. Hausman is to check whether fixed effects is better than random effects. F_2 is to check the time fixed effects. F_3 is to check serial correlation. X_1 is to check cross-sectional correlation, and X_2 is to check cross-sectional heteroscedasticity. The numbers in brackets are P values; "*", "**", "***" represent the rejection of the null hypothesis at the significant level of 10%, 5%, and 1%, respectively.

In order to take into account the cross-sectional heteroscedasticity so as to fully reveal the role of port-city coordination in economy development for different port cities, varying-coefficient model is introduced on the basis of the fixed effects model. The adjusted partial varying-coefficient model form is as the following:

$$\begin{aligned}\text{ln_GDP}_{it} = {} & \alpha_0 + \alpha_i^* + \alpha_{1i}\text{port_city_coor}_{it} + \alpha_2\text{dln_fasset_investment}_{it} \\ & + \alpha_3\text{ln_labor}_{it} + \alpha_4\text{ln_freight_turnover}_{it} + \varepsilon_{it} \\ & (i = 1, 2, \ldots, 9,\ t = 1, 2, \ldots, 15)\end{aligned} \tag{8}$$

$$\begin{aligned}\text{ln_GDP}_{it} = {} & \beta_0 + \beta_i^* + \beta_{1i}\text{port_city_coor}_{it-1} + \beta_2\text{dln_fasset_investment}_{it} \\ & + \beta_3\text{ln_labor}_{it} + \beta_4\text{ln_freight_turnover}_{it} + \varepsilon_{it} \\ & (i = 1, 2, \ldots, 9,\ t = 1, 2, \ldots, 15)\end{aligned} \tag{9}$$

In Formulae (8) and (9), α_i^* and β_i^* are the fixed-effect intercepts for different port cities. Model (8) uses α_{1i} to reveal the impact of the current port-city synergy degree ($\text{port_city_coor}_{it}$) on the GDP corresponding to different port cities. Model (9) uses β_{1i} to reveal the influence of the first lag of port-city synergy degree ($\text{port_city_coor}_{it-1}$) on the GDP corresponding to different port cities. The other coefficients and variables mean the same as in Models (6) and (7). Similarly, Model (9) works as a robustness verification of Mode (8). The estimation results of Models (8) and (9) are shown in Table 4.

The synergy degree coefficients α_{1i}, β_{1i}, and the fixed-effect intercepts α_i^*, β_i^*, are shown in Table 5.

In Table 4, the coefficient of capital increment is positive and significant at 5%, while the coefficient of labor input is negative and insignificant, indicating that among the nine cities in Pearl River Delta, the increase in capital casts a greater impact on urban economic growth than labor input does. In Table 5, most of the fixed-effect intercepts

TABLE 4. Common coefficients and estimation results

Variables	Model (8)	Model (9)	Variables	Model (8)	Model (9)
$\text{port_city_coor}_{it}$	3.353^{***}		$\text{ln_freight_turnover}_{it}$	0.032	0.090^{*}
	(16.99)			(1.74)	(2.08)
$\text{port_city_coor}_{it-1}$		2.315^{***}	Intercept	6.521^{***}	7.007^{***}
		(8.92)		(29.73)	(30.66)
$\text{dln_fasset_investment}_{it}$	0.166^{**}	0.209^{**}	R square	0.9816	0.9795
	(2.76)	(2.87)			
ln_labor_{it}	-0.015	-0.031			
	(-0.57)	(-1.57)			

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

TABLE 5. Fixed-effect intercepts and port-city synergy degree coefficients

Ports	Model (8)		Model (9)	
	α_{1i}	α_i^*	β_{1i}	β_i^*
Guangzhou	3.3528^{***}	6.5212^{***}	2.3153^{***}	7.0073^{***}
	(16.99)	(29.73)	(8.9)	(30.66)
Foshan	5.4868^{***}	5.6036^{***}	5.8463^{***}	5.6162^{***}
	(15.95)	(8.33)	(24.26)	(23.96)
Shenzhen	3.9475^{**}	6.0251^{***}	2.9878^{***}	6.5110^{***}
	(3.08)	(4.03)	(3.96)	(5.86)
Zhuhai	2.5091^{***}	5.3800^{***}	2.3935^{***}	5.3196^{***}
	(5.69)	(12.89)	(0.33)	(33.50)
Dongguan	1.7082^{***}	7.1910^{***}	1.4640^{***}	7.1913^{*}
	(10.61)	(6.93)	(8.52)	(2.22)
Jiangmen	2.5088^{***}	5.0162^{***}	2.2423	5.0496^{***}
	(4.55)	(12.63)	(0.48)	(25.61)
Huizhou	2.9678^{**}	4.7471^{***}	2.5169^{*}	4.9386^{***}
	(2.34)	(15.48)	(1.88)	(21.81)
Zhongshan	4.4807^{***}	5.2843^{***}	3.9241^{***}	5.4406^{***}
	(4.67)	(7.43)	(10.47)	(13.13)
Zhaoqing	4.4151^{***}	3.7061^{***}	3.8339^{***}	3.9345^{***}
	(5.85)	(23.46)	(7.95)	(42.54)

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

and port-city synergy degree coefficients are significant, reflecting that the model setting of partial varying-coefficient model is reasonable.

Besides, all the port-city synergy degree coefficients are positive, showing that port-city coordination plays a positive role in hinterland economic development, whereas the coefficients vary corresponding to different port cities, indicating that the effects of coordination vary in different port cities. In particular, the effect is more intense in Foshan, Zhongshan, and Zhaoqing, less obvious in Shenzhen and Guangzhou, even weaker in Huizhou, Zhuhai, Jiangmen, and Dongguan. To demonstrate, Foshan, Zhongshan, and Zhaoqing are inland river ports, where urban economy is highly dependent on ports, thus port-city coordination has greater effects on regional economic growth, while in Shenzhen and Guangzhou, although urban economy is developed and less dependent on port economy, port-city coordination provides a better environment for industrial agglomeration, and therefore has

a certain effect on urban economy. As for the emerging coastal manufacturing centers such as Dongguan and Huizhou, urban economy is motivated mainly by local industries, and the port-city coordination exerts a relatively small impact.

In addition, the estimation results of Model (8) and Model (9) are very similar; thus, Model (8) and Model (9) can mutually confirm the robustness of each other.

4. **Conclusions.** This paper first constructs a port-city composite system synergy model, followed by calculating the synergy degrees of 9 port cities in the Pearl River Delta from 2005 to 2019. Subsequently, the panel data of the calculated port-city synergy degrees and other macro-level variables are utilized to establish a panel measurement model, so as to further study the impact of the port-city coordination on regional economic growth. Through empirical analysis, the following conclusions are drawn. 1) Although the port-city synergy degrees are all rising during the 15 years, the growing extent is not balanced when it comes to different ports. In general, the coordination development of inland river ports is not as good as that of other coastal ports. 2) The port-city coordination exerts positive effects on urban economy in both the present and the long run. 3) The importance of the port-city synergy degree is different among different port cities. As an illustration, for inland river ports such as Foshan, in which urban economy depends more on port service, the port-city synergy degrees have the greater effects on promoting urban economy than other ports. For regional hub such as Shenzhen, in which the coordinated port-city can provide a better environment for the industrial agglomeration and urban economy development, the port-city synergy degrees play a secondary role. For emerging manufacturing centers such as Dongguan, in which other industries such as manufacturing and tourism provide new pillars for urban economic growth, port-city synergy degrees exert a smaller impact on economic growth than other ports. 4) Capital increment is a greater driver to promote urban economic growth than labor input, which suggests that the industries in the Pearl River Delta have upgraded to capital intensive industries, thus capital investment can bring better results.

These conclusions provide policy enlightenment for differently positioned ports to adopt different port-city coordination strategies. Inland ports such as Foshan, Zhongshan and Zhaoqing, are suggested to continue to upgrade hinterland industry, strengthen the integration of regional port resources, and further enhance the coordinated development of port and urban economy, while emerging manufacturing center ports such as Huizhou, Zhuhai, Jiangmen, and Dongguan, are suggested to optimize the connectivity between ports and hinterland transportation, and improve port services to serve the hinterland industrial output.

The research of this paper still has the limitation of leaving the cross-sectional correlation unsolved. The authors will further study on the limitation in the future.

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