Spatial Effects of Port-City Coordination on Urban Economic Growth

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Abstract. Quantitative empirical research on port-city coordinated development holds significant strategic implications for regional economic growth. Taking Guangdong Province, China, as an example, this paper constructs a coupling coordination degree model and a spatial Durbin model based on the "port-city" composite system theory to empirically analyze the spatiotemporal evolution characteristics of port-city coordination levels from 2013 to 2022 and their spatial effects on urban economic growth. The findings reveal that Guangdong's port-city coordination exhibits a spatial pattern of "high in the Pearl River Delta (PRD), low in eastern, western, and northern Guangdong." The dynamic coordination degree indicates an overall optimization trend, though with periodic fluctuations and localized deterioration. Spatial effect analysis demonstrates that port-city coordination significantly promotes local economic growth, with capital stock and transport density being key driving factors.

Keywords: Port-city coordination; Spatial effects; Economic growth; Coupling coordination degree model; Spatial Durbin model.

1 Introduction

Against the backdrop of global trade network restructuring and increasing demands for supply chain resilience, ports, as strategic pivots for regional economic development, serve as critical platforms for cities to engage in international division of labor. Taking the Yangtze River Delta port cluster as an example, it not only supports industrial upgrading in the Yangtze River Delta urban agglomeration but also extends its influence to 16 inland provinces, creating an open development pattern characterized by "land-sea synergy and dual-circulation connectivity" [1]. The coordinated development of ports and cities has emerged as a central theme for high-quality regional economic growth in the new era. Successful port-city coordination example include Singapore and Rotterdam. The former combined the Jurong Industrial Estate, Marina Bay and Pasir Panjang port to form a model where efficient logistics and livable cities coexist via refined urban planning [2]. The latter expanded its port through the Maasvlakte 2 reclamation project, while transforming the old harbor area of the inner city (e.g., Rijnhaven) into a mixed-use area [3]. Challenges faced by peripheral cities include industrial siphon effect [4], and social exclusion and inequality due to unequal

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distribution of port dividends and limited employment opportunities in surrounding communities [5].

This study employs a coupling coordination degree model to conduct quantitative analysis of port-city coordination levels across prefecture-level cities in Guangdong Province. By integrating an indicator evaluation system with Moran’s I index, the research reveals the spatial distribution characteristics of port-city coordinated development. A spatial Durbin model (SDM) is constructed to analyze the spatial spillover effects of port-city coordination on economic growth, which can more accurately capture spatial data effects [6]. Furthermore, the model distinguishes between local direct effects and neighboring indirect effects, elucidating the interactive relationship between port and urban economic growth. By quantifying these spillover effects, the study offers theoretical support for understanding how port-city coordination drives regional economic development.

2 Research Region and Data

Guangdong's port system exhibits a multi-tiered and specialized development pattern, revealing significant regional imbalances: the Guangdong-Hong Kong-Macao Greater Bay Area ports show excessive agglomeration, with Guangzhou, Shenzhen and Hong Kong ports collectively contributing over 65% [7], while western and eastern Guangdong ports lag behind in development. This "core-periphery" spatial structure provides a good example for studying the economic effects of port-city coordination levels.

During data collection, issues such as incomplete statistics and unverifiable data were encountered for some smaller ports. Considering these limitations, the research ultimately selected six major cities and their corresponding ports in Guangdong for analysis. The Pearl River Delta region's Guangzhou, Shenzhen, Zhuhai, and Dongguan, with their advanced economic development and well-established port infrastructure, along with Shantou Port in eastern Guangdong and Zhanjiang Port in western Guangdong as key port cities, were chosen as representative samples. Original data for various indicators were sourced from the China City Statistical Yearbook, China Port Statistical Yearbook, and municipal statistical bulletins spanning 2013 to 2022, ensuring comprehensive and authoritative data coverage for the study's empirical analysis.

3 Methodology

3.1 Port-City Coordination Measurement Indicator System

The construction of a port evaluation indicator system must comprehensively consider both the port's own operational capabilities and the urban development's support and coordination with the port, quantifying port-city interaction effectiveness through a multi-level indicator framework. Adhering to the principles of data availability and scientific rigor, and referencing existing research [8], the comprehensive strength assessment of the port subsystem was conducted as in Table 1, with all indicator weights calculated using the entropy weight method.

Table 1. Port Logistics Evaluation Indicator System (weights via the entropy weight method)

Sub-system	Division	Indicator/unit	Weight
Port	Infrastructure Condition	berth length / meter	0.20
		number of berths / count	0.20
	TEU Throughput	Ten thousands of TEU	0.30
	Cargo Throughout	Ten thousand of tons	0.30
City	Economic	per capita GDP (Yuan)	0.25
		retail sales of consumer goods (10^8 Yuan)	0.20
	Trade with Foreign Countries	foreign-invested enterprises (count)	0.15
		total import-export volume (10^8 Yuan)	0.30
	Environment	green space area (ha)	0.10

3.2 Coupling Coordination Degree Model

Coupling Coordination Degree Model is mainly used for quantitatively assessing the level of synergistic development between ports and urban systems. Its application can be found in comparative study of international port cities [9], and port-city integration at different spatial scales[10]. To achieve an accurate assessment of the synergistic development between port and city, it is necessary to construct a comprehensive evaluation model that integrates both static and dynamic coordination indicators for systematic analysis.

Static Coordination Degree. Based on the indicator weights presented in Table 1, the comprehensive evaluation indices for the *i*-th port subsystem (S1) and urban subsystem (S2) are calculated respectively.

$$S_1 = \sum_{\alpha=1}^{n_1} w_\alpha r_{i\alpha}, \quad S_2 = \sum_{\beta=1}^{n_2} q_\beta e_{i\beta} \tag{1}$$

where α represents a specific indicator of the port subsystem, β denotes a particular indicator of the urban subsystem, w_α signifies the weight value of each indicator in the port subsystem, $r_{i\alpha}$ stands for the standardized data of each indicator in the port subsystem, q_β indicates the weight value of each indicator in the urban subsystem, and $e_{i\beta}$ refers to the standardized data of each indicator in the urban subsystem. Subsequently, the physical coupling model is introduced to measure the static coordination level between ports and cities in Guangdong, with its calculation formula expressed as:

$$C = \sqrt{\frac{S_1 S_2}{\left(\frac{S_1+S_2}{2}\right)^2}};\ D = \sqrt{CQ};\ Q = aS_1 + bS_2 \tag{2}$$

where C denotes the coupling degree; D represents static and coupling degree; Q signifies the comprehensive development index of port-city coordination level; a and b are the weighting coefficients of each subsystem with a+b=1. The classification of static coupling coordination types is determined based on criteria established through the uniform distribution function method.

Dynamic Coordination Degree. The dynamic coordination degree provides a more effective representation of the evolving trends in coordination between port and urban subsystems, which can be expressed by the following formula.

$$U_d = \frac{U_t}{U_{t-1}} \tag{3}$$

where U_d represents the dynamic coordination degree; U_t denotes the static port-city coordination degree at time t; U_{t-1} indicates the static port-city coordination degree at time t−1, with the dynamic coordination degree being evaluated according to the classification criteria specified as follows: U_d=1 means stable, U_d<1 means better, and U_d>1 means worse.

3.3 Spatial Durbin Model (SDM)

The application of Spatial Durbin Model (SDM) mainly focuses on analyzing the spatial spillover effects, cross-regional interaction mechanisms and policy implications of port and city development. This study employs the SDM to investigate the spatial effects of Guangdong Province's port-city coordination level on urban economic growth, encompassing both direct effects and indirect spillover effects.

This study constructs the following Spatial Durbin Model (SDM):

$$\ln Y_{it} = \alpha + \beta_1 \ln D_{it} + \beta_2 \ln K_{it} + \beta_3 \ln T_{pit} + \beta_4 \ln P_{eit} + \beta_5 \ln T_{rit} + \beta_6 \ln L_{it} + \beta_7 \sum_{j=1}^{n} w_{ij} \ln D_{jt} + \beta_8 \sum_{j=1}^{n} w_{ij} \ln K_{jt} + \beta_9 \sum_{j=1}^{n} w_{ij} \ln T_{pjt} + \beta_{10} \sum_{j=1}^{n} w_{ij} \ln P_{ejt} + \beta_{11} \sum_{j=1}^{n} w_{ij} \ln T_{rjt} + \beta_{12} \sum_{j=1}^{n} w_{ij} \ln L_{jt} + \rho \sum_{j=1}^{n} w_{ij} \ln Y_{jt} + \mu_i + \lambda_t + \varepsilon_{it} \tag{4}$$

Where i and j denote sample units (specifically the i-th and j-th ports); t represents the time dimension, Y is Per capita GPD, D is Port-city coordination, K is total import-export volume, T_p is Ratio of urbanization, P_e is square of traffic network and T_r is Population density.

4 Results and Discussion

4.1 Spatiotemporal Evolution Characteristics of Port-City Coordination Level

Spatiotemporal Distribution of Static Coordination Level. Fig.1 presents the spatiotemporal evolution characteristics of static coordination degree in selected Guangdong Province cities, revealing the following patterns: core cities like Shenzhen and Guangzhou demonstrate significantly higher coordination degrees compared to Zhanjiang and Shantou. The heatmap reveals that Shenzhen, Guangzhou, and Zhuhai have experienced consistent annual improvements in coordination degree since 2017.

Evolution of Dynamic Coordination Level. The dynamic coordination level analysis reveals that Zhuhai and Dongguan experienced rapid improvement post-2018, with

Shenzhen, Guangzhou, and Zhuhai entering the "highly coordinated" threshold by 2022. The evolutionary trends of dynamic coordination degree (Table 2) demonstrate the combined effects of policy drivers and regional economic integration.

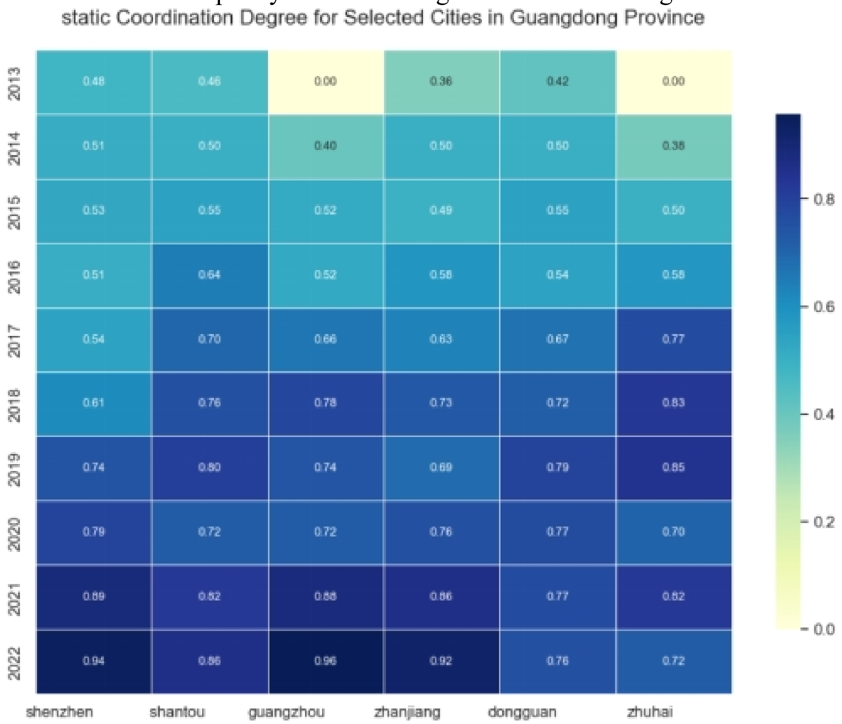

Fig. 1. Trend of Static Coordination Level in the Selected Cities in Guangdong

Table 2. Results of Dynamic Coordination Level

Port-city	Shenzhen	Guang-	Zhuhai	Dongguan	Shantou	Zhanjiang
2014	1.06	/	/	1.20	1.09	1.41
2015	1.03	1.29	1.33	1.09	1.09	0.99
2016	0.96	1.00	1.16	0.99	1.18	1.17
2017	1.07	1.27	1.34	1.24	1.09	1.09
2018	1.12	1.19	1.07	1.07	1.08	1.16
2019	1.22	0.95	1.02	1.10	1.06	0.94
2020	1.06	0.97	0.83	0.97	0.90	1.10
2021	1.12	1.21	1.17	1.00	1.14	1.14
2022	1.06	1.06	0.88	0.98	1.05	1.07
Average	1.08	1.12	1.10	1.07	1.08	1.12

Empirical Results of Spatial Durbin Model. Using STATA, we estimated various specifications of the spatial panel Durbin model including time-fixed, random effects, individual-fixed, and dual-fixed effects. Consequently, we construct a spatial panel Durbin model incorporating time-fixed effects and decompose both direct and indirect effects, with the decomposed economic impacts of each variable on urban economies presented in Table 3. As shown in Table 3, capital stock uniformly promotes growth through both direct and indirect channels, solidifying its role as a key driver of port-city coordination and regional development.

Table 3. Decomposition of Spatial Spillover Effects from Spatial Panel Durbin Model Coefficients

	LR_Direct	LR_Indirect	LR_Total
D	0.2240***	-0.0367	0.1873
	(2.7626)	(-0.3056)	(1.1833)
lnL	-0.2110**	-0.1126	-0.3236
	(-2.2563)	(-0.4556)	(-1.0947)
Pe	0.0165***	0.0262	0.0428
	(3.0925)	(1.0293)	(1.6217)
lnTR	0.0098	-0.0263	-0.0165
	(0.6261)	(-0.6117)	(-0.3502)
lnTp	0.0084	-0.0463	-0.0379
	(0.1634)	(-0.5850)	(-0.4480)
lnK	0.2125***	0.3317***	0.5442***
	(4.5451)	(3.4981)	(4.2433)

4.2 Analysis of Influencing Factors

The aforementioned empirical results demonstrate that port-city coordination significantly promotes local economic growth, while capital stock and transport density exhibit differentiated characteristics in terms of both local and indirect effects. The spatial spillover pathways further reveal the complex mechanisms underlying regional synergy.

Capital stock, technological investment, and transport density are the core drivers through which port-city coordination affects urban economic growth. The significantly positive direct and indirect effects of capital stock indicate that capital accumulation generates strong positive spillover effects through cross-regional industrial chain extension and resource sharing.

4.3 Potential Policy

To help stakeholder better implement strategies for enhancing port-city collaboration, potential policies according to the above findings are listed as follows. First, cross-regional integration focusing on capital and transportation. Second, administrative barriers need to be broken down and a dynamic monitoring mechanism established.

Third, the core area of the PRD can pilot the enclave economy and promote benefit sharing in port alliances.

5 Conclusions

This study empirically analyzes the spatial effects of port-city coordination on urban economic growth in Guangdong Province through the construction of a coupling coordination degree model and a Spatial Durbin Model. The findings reveal significant spatial disparities in port-city coordination levels across Guangdong Province. This disparity reflects unbalanced development in port-city coordination across regions. It further demonstrates the significant positive impact of port-city coordination on local economic growth. The model identifies capital stock and transport density as key drivers facilitating the relationship between port-city coordination and economic growth. Spatial spillover effect analysis reveals that port-city coordination not only directly affects local economies but also generates indirect spillover effects on neighboring regions.

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