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Measurement of Economic Synergistic Development of the East and West Coasts of the Pearl River Estuary and Its Spatial and Temporal Evolution Based on DEA

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ABSTRACT
In the context of the Guangdong-Hong Kong-Macao Greater Bay Area becoming a national strategy, it is of significance to study the economic synergistic development of the east and west coasts of the Pearl River Estuary in order to promote the synergistic and integrated development of the Greater Bay Area. The prerequisite for achieving synergistic development lies in the scientific and reasonable evaluation of synergistic development. With the use of an extended DEA model, this study explores the economic synergistic development of the east and west coasts of the Pearl River Estuary from 2010 to 2019, and reveals its spatial and temporal evolution characteristics. According to the research results, the economic synergistic development of the east and west coasts of the Pearl River Estuary has just entered the middle and advanced stage of symbiotic development during ten years, and has not yet reached DEA validity. The degree of economic synergetic development on the east coast is higher than that on the west coast, and the gap is widening. The level of economic synergistic development on both coasts shows a general upward trend, with small fluctuations in individual years. At the same time, it has obvious spatial clustering, showing the characteristics of high in the east and low in the west and clustering distribution towards the inlet.

Keywords: *East and west coasts of the Pearl River Estuary, Economic synergistic development, Synergy validity.*

1. INTRODUCTION

According to the report of the 19th National Congress of the Communist Party of China, socialism with Chinese characteristics has entered a new era, and economic growth has shifted from high-speed growth to high-quality development. Regional economic development has gone through "regional balance", "regional unbalance", "regional coordination" and "regional integration", and has entered the stage of "regional synergy" [1]. The Pearl River Delta is located at the Pearl River Estuary, and its geographical area is in the shape of an isosceles triangle, bounded by the apex of Guangzhou, with Guangzhou, Foshan and Zhaoqing in the middle, Shenzhen, Dongguan and Huizhou on the east coast of the Pearl River Estuary, and Zhuhai, Zhongshan and Jiangmen on the west coast of the Pearl River Estuary. The Pearl River Delta, as a pioneering zone of China's reform and opening up, is one of the three major urban agglomerations with the largest population aggregation, the strongest innovation capacity and the most comprehensive strength in China. In 2019, the regional GDP in Pearl River Delta was RMB 868,905 billion, accounting for 8.8% of the country's GDP. However, the economic development within the Pearl River Delta is uneven, with cities on the east coast developing faster than those on the west coast for a long time. In 2019, the GDP of Shenzhen, Dongguan and

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Huizhou on the east coast of the Pearl River Estuary was 4058.7 billion yuan, and the per capita GDP was 151538 yuan. The GDP in the middle area on the west coast of the Pearl River Estuary was only 968.3 billion yuan, and the per capita GDP was 10000 yuan. The gap in economic development gradually widened, which attracted extensive attention of the government and academia. During a visit to Guangdong in 2018, General Secretary Xi Jinping asked Guangdong to accelerate the formation of a new pattern of coordinated regional development and to make the Pearl River Delta better and stronger. "The Outline for the Development of the Guangdong-Hong Kong-Macao Greater Bay Area" clearly proposes to "raise the development level of the west coast of the Pearl River and promote the synergistic development of the east and west coasts". In addition, "the implementation opinions of the CPC Guangdong Provincial Committee on the implementation of the decision of the CPC Central Committee on several major issues concerning upholding and improving the socialist system with CPC characteristics and promoting the modernization of the national governance system and governance capacity", "report on 2019 national economic and the implementation of social development plan of Guangdong Province and the 2020 draft plan", as well as "several measures for Guangdong Province to establish and improve the institutional mechanism and policy system for integrated urban and rural development", propose to promote the coordinated development of the east and west coasts of the Pearl River Estuary. Therefore, against the current background, it is of great practical value to evaluate and study the level of economic synergetic development of the east and west coasts of the Pearl River Estuary, to make the pearl River Estuary a better and stronger core area, and to promote the synergetic and synergetic development of the Guangdong-Hong Kong-Macao Greater Bay Area.

At present, the theoretical research on the synergetic development of regional economy in academic circles mainly focuses on the theoretical basis, connotation, basis and promotion principles of the synergetic development of regional economy, such as the operation and driving mechanism of the synergetic development of economic system [2], [3], [4], [5], [6]. As for the research on the synergetic development of the east and west coasts of the Pearl River, Ma Lili [7] studied the process, influencing factors and future trend of regional differentiation and synergetic development of the east, middle and west coasts of the Pearl River Delta since the reform and opening up. Cai Peilin and Zeng Yanying [8] studied the impact of the construction of Hong Kong-Zhuhai-Macao Bridge on the port construction and economic synergetic development on the east and west coasts of the Pearl River Estuary. Qu Lili [9] made a comparative study on the formation, characteristics, transformation, upgrading and synergetic development path of the development model of industrial clusters on the east and west coasts of the Pearl River Estuary. With the use of panel data analysis, Xu Ping [10] found that consumption demand, human capital and fixed asset investment were the main factors affecting the synergetic development of the east and west coasts of the Pearl River. At present, there is no evaluation study on the degree of economic synergetic development of the east and west coasts of the Pearl River Estuary.

Therefore, using the panel data of the east and west coasts of the Pearl River Estuary from 2010 to 2019 and the extended DEA model, this study makes a dynamic evaluation and comparative analysis on the regional economic synergistic development of the east and west coasts of the Pearl River Estuary in the past 10 years, and reveals the dynamic characteristics and prominent problems of the economic synergistic development of the east and west coasts of the Pearl River Estuary. Finally, the policy enlightenment to promote the economic synergistic development of the east and west coasts of the Pearl River Estuary is obtained.

2. RESEARCH METHODS AND INDICATOR SYSTEM

2.1 Research Methods

This study explores the degree of economic synergistic development among subsystems in the region. Drawing on Du Zhiping's and Mu Dong's [11] extended DEA model, it is found that the systematic synergistic evolution is the result of synergy and development promoting each other, and development cannot be achieved without synergy, while synergy without development is meaningless. Therefore, the overall validity of inter-system synergetic development indicates that "inter-system synergy validity" and "inter-system development validity" exist simultaneously, and the value of integrated validity of systematic synergistic is the product of systematic synergistic validity and systematic development validity. The evaluation procedures are as follows.

- Evaluating the synergistic validity and developmental validity of the regional economic subsystems.

$h_e(A/B)$ represents the degree of synergistic efficiency between regional economic subsystem A and subsystem B.

$$h_e(A/B)=\{\min[h_e(A/B), h_e(B/A)]\}/\{\max[h_e(A/B), h_e(B/A)]\} \quad (1)$$

$$f_e(A/B)=\{\min[f_e(A/B), f_e(B/A)]\}/\{\max[f_e(A/B), f_e(B/A)\} \quad (2)$$

- Evaluating the comprehensive effectiveness of synergistic development among regional economic subsystems.

zh_e (A/B) represents the comprehensive effectiveness of synergistic development among regional economic subsystems, and the computational formula is as follows:

$$zh_e(A/B) = h_e(A/B)\times f_e(A/B) \quad (3)$$

- Evaluating the synergistic validity he (A, B, C) and developmental validity fe (A, B, C) among the three systems.

$$he(A, B, C)=[\sum he(A/B, C)\times he(B, C)]/\sum he(B, C) \quad (4)$$

$$fe(A, B, C)=[\sum fe(A/B, C)\times fe(B, C)]/\sum fe(B, C) \quad (5)$$

- Evaluating the synergistic validity he (1, 2,..., K) and developmental validity Fe (1, 2,..., K) among K systems.

$$h_e(1,2,\cdots,k) = \frac{\sum_{i=1}^{k} h_e(i/i_{k-1})\times h_{ek-1}(i_{k-1})}{\sum_{i=1}^{k} h_{ek-1}(i_{k-1})} \quad k=3,4,\cdots,m \quad (6)$$

$$f_e(1,2,\cdots,k) = \frac{\sum_{i=1}^{k} f_e(i/i_{k-1})\times f_{ek-1}(i_{k-1})}{\sum_{i=1}^{k} f_{ek-1}(i_{k-1})} \quad k=3,4,\cdots,m \quad (7)$$

$0<zh_e<1$, zh_e is close to 1, indicating that the synergistic effect between A system and B system is good. zh_e is close to 0, indicating that the synergistic effect between A system and B system is bad. Therefore, the range of comprehensive validity of inter-regional economic synergetic development is (0,1). The synergy value is divided into 4 stages on average corresponding to the synergy development level, that is, (0-0.25] is the primary synergetic stage, (0.25-0.5] is the intermediate synergetic stage, (0.5-0.75] is the intermediate and advanced synergetic stage, and (0.75-1) is the advanced synergetic stage.

2.2 Indicator System

Synergetic development of regional economy refers to a regional economic development model in which regions or subsystems within the same region work together to promote the large regional economy change from being disordered to being ordered, and from being primary to being advanced, form an endogenous growth mechanism of mutual benefit, and finally promote the efficient and sustainable development of large regional economy. The main performance characteristics of regional economic synergetic development are the symbiosis among various economic subsystems, the efficiency of the whole system and the dynamics of economic development process [12], which are influenced by regional economic development gap, comparative advantage and factor flow. The comprehensive validity of regional economic synergetic development is evaluated from two dimensions: performance characteristics and influencing factors. The performance characteristics are output indicators and the influencing factors are input indicators. The performance characteristics are measured by three indicators: regional economic relation, regional economic growth and regional economic efficiency. The influencing factors are measured by three indicators: regional economic development gap, regional comparative advantage and regional factor flow.

Table 1. Evaluation indicator system of regional economic synergistic development

Classification of indicators	first-grade indicator	secondary indicator	Indicator Formulas
input indicators	Regional Development Gap	X_1 GDP as a share of total economy	$R_i=\frac{GDP_i}{GDP}$ GDP_i represents the GDP of i, and GDP refers to the gross regional product of the east and west coasts of the Pearl River Estuary.
	Regional comparative advantages	X_2 Comparative labour productivity	$CLP_i=\frac{GDP_i/GDP}{Labor_i/Labor}$ GDP_i represents the GDP of i, and GDP refers to the gross regional product of the east and west coasts of the Pearl River Estuary. $Labor_i$ represents the quantity of employment in i at the end of year, and labor represents the quantity of employment of the east and west coasts of the Pearl River Estuary at the end of year.
	Regional Factor Flows	X_3 Regional trade dependence	$RTD_i=\frac{Br}{GDP}=\frac{N_i-B_i}{GDP_i}$ N_i represents the net outflow of goods and labor services in i, B_i represents the balance of international trade in i, and GDP_i represents the GDP of i.
output indicators	Regional economic growth	X_4 growth rate of per capita GDP	$G_{it}=\frac{P_{it}-P_{i(t-1)}}{P_{i(t-1)}}\times 100\%$ P_{it} represents the per capita GDP of i in t year, $P_{i(t-1)}$ represents the per capita GDP of i in the year of t-1.
	Regional economic efficiency	X_5 Social labor productivity	$SLP_i=\frac{GDP_i}{Labor_i}$ GDP_i represents the GDP of i, $Labor_i$ represents the average number of social workers in i.
	Regional economic relation	X_6 Strength of urban economic relation	$C_j=\sum_{i=1}^{n}C_{ij}=\sum_{i=1}^{n}\frac{\sqrt{G_iP_i\times G_jP_j}}{D_{ij}^2}$ P_i, P_j represents the permanent resident population in i and j at the end of year, G_i, G_j are the GDP of two cities, D_{ij} refers to the distence between the two cities.

2.3 Data Source and Processing

All the original data used in this study are from "the statistical yearbook of Guangdong from 2011 to 2020" and "the statistical yearbook of cities on the east and west coasts of the Pearl River Estuary". The winsorization is taken at the level of 1% of the variables involved, and the extended DEA method is used to comprehensively evaluate the economic synergetic development level of cities on the east and west coasts of the Pearl River from two aspects of synergy and development. Finally, the comprehensive validity value of the economic synergetic development of cities on the east and west coasts of the Pearl River Estuary from 2010 to 2019 is obtained (see "Table 2").

Table 2. Comprehensive validity of economic synergetic development of the east and west coasts of the Pearl River Estuary from 2010 to 2019 and its ranking

City/Region	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	mean value	Ranking
Shenzhen	0.44	0.30	0.34	0.39	0.62	0.56	0.78	0.75	0.87	0.89	0.59	1
Huizhou	0.48	0.39	0.37	0.39	0.41	0.44	0.47	0.58	0.51	0.64	0.47	5
Dongguan	0.63	0.50	0.42	0.45	0.38	0.44	0.61	0.72	0.57	0.76	0.55	2
Pearl River Estuary East Coast Mean	0.52	0.40	0.38	0.41	0.47	0.48	0.62	0.68	0.65	0.76	0.54	
Zhuhai	0.69	0.56	0.39	0.43	0.53	0.41	0.47	0.42	0.68	0.71	0.53	3
Zhongshan	0.47	0.38	0.33	0.27	0.34	0.42	0.45	0.48	0.44	0.50	0.41	6
Jiangmen	0.54	0.50	0.32	0.43	0.46	0.55	0.57	0.66	0.58	0.61	0.52	4
Pearl River Estuary West Coast Mean	0.57	0.48	0.35	0.38	0.44	0.46	0.50	0.52	0.57	0.61	0.49	
Pearl River Estuary Mean	0.54	0.44	0.36	0.39	0.46	0.47	0.56	0.60	0.61	0.69	0.51	

3. EMPIRICAL ANALYSIS

3.1 Analysis on Comprehensive Validity of Economic Synergistic Development of the East and West Coasts of the Pearl River Estuary

From 2010 to 2019, the comprehensive validity value of synergetic development of cities on the east and west coasts of the Pearl River Estuary in recent 10 years was greater than 0.30. All cities were in the stage of synergetic development above the intermediate level, but there was no value above 0.90, which had not yet reached the DEA validity. Zhuhai (0.89) in 2019 had the highest synergetic development value, which entered the advanced synergetic development stage. The lowest value of synergetic development was Zhongshan (0.27) in 2013, which just entered the intermediate synergetic development stage.

The mean comprehensive validity of the economic synergetic development of the east and west coasts of the Pearl River Estuary was 0.51, indicating that the economic synergistic development of the east and west coasts of the Pearl River Estuary was in the middle and advanced symbiotic development stage. From a regional perspective, the highest average value of synergetic development validity in the past 10 years was 0.59 (Shenzhen), followed by 0.55 (Dongguan), and the lowest was 0.41 (Zhongshan). The average value of regional economic synergetic development on the east coast of the Pearl River Estuary was 0.54 in 10 years, which was higher than 0.51 on the west coast, and the relative gap was 1.05. It could be seen that the export-oriented characteristics of the economic development of the east and west coasts of the Pearl River Estuary were still obvious, the degree of synergetic, efficient and orderly economic development of the two coasts was not enough, and there were great regional differences.

3.2 Analysis on the Evolution Trend of Economic Synergistic Development of the East and West Coasts of the Pearl River Estuary

Over the past 10 years, the economic synergistic development of the east and west coasts of the Pearl River Estuary has shown an overall upward trend, with slight fluctuations in individual years ("Figure 1"). The level of synergistic development increased from 0.47 to 0.69, with an increase rate of 46.8%, from the intermediate synergistic development stage of diffusion to the intermediate and advanced synergistic development stage of symbiosis. The change trend is divided into two stages during the investigation period. The first stage was 2010-2012, showing a downward trend, from 0.47 in 2010 to the highest peak of 0.36 in 2012. The second stage was 2012-2019, during which the synergetic development of regional economy was in a steady upward trend, and this stage gradually increased from 0.36 in 2012 to 0.69 in 2019. The evolution trend of the comprehensive validity of the economic synergetic development of various cities was basically consistent with the overall synergetic evolution trend of the two coasts. The city with great fluctuation was Shenzhen, which continued to rise to 0.89 in 2019 after a slight decline from 0.44 in 2010 to 2011. It gradually entered the advanced stage from the intermediate diffusion stage of synergetic development, with the largest increase in the degree of synergetic development, and the increase rate of the synergetic development reached 102%. The level of synergetic development in Zhongshan had changed the least. It has been in the intermediate diffusion stage for 10 years, and the evolution trend is the most stable.

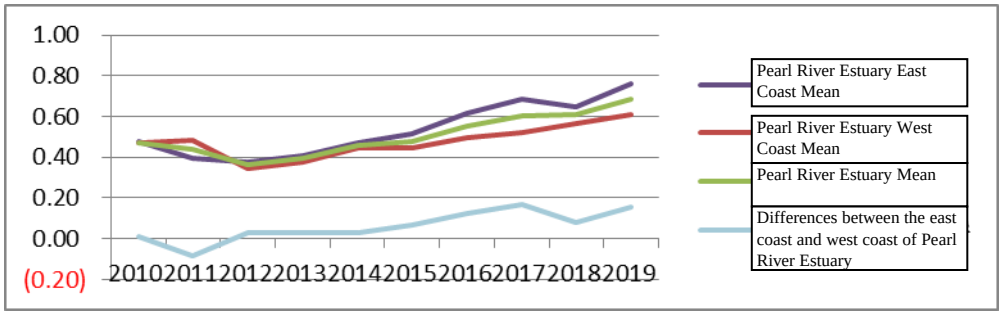

Figure 1 The evolution trend of economic synergetic development on the east and west coasts of the Pearl River Estuary from 2010 to 2019.

Over the past 10 years, the gap in the level of economic synergistic development of the east and west coasts of the Pearl River Estuary has shown an expanding trend as a whole (Figure 1). Specifically, in 2010, the degree of economic synergistic development on the east coast of the Pearl River Estuary was 0.48 and that on the west coast was 0.47. The level of economic synergistic development on both coasts was in the intermediate diffusion stage, which was basically the same. In 2011, the degree of economic synergetic development in the west coast was 0.44, which was higher than 0.40 in the east bank. After 2011, the degree of economic synergetic development on the east bank continued to be higher than that on the west coast, and the gap in economic synergetic development of the two coasts gradually expanded, reaching the largest in 2017, with a relative gap of 1.31. In 2017, "government work report" proposed to "study and formulate the development plan of Urban Agglomeration of Guangdong-Hong Kong-Macao Greater Bay Area", the gap in economic synergetic development of the two coasts was narrowed in 2018, but it expanded in 2019. It was found that there were different effects of a series of policies to promote the economic synergetic development of the east and west coasts of the Pearl River Estuary on cities, with better effects on cities on the east coast and limited effects on cities on the west coast.

3.3 Spatial Differentiation Characteristics of the Economic Synergetic Development of the East and West Coasts of the Pearl River Estuary

According to the spatial distribution map of the economic synergistic development of the east and west coasts of the Pearl River Estuary in 2010, 2015 and 2019 ("Figure 2"), the level of the economic synergistic development of the east and west coasts of the Pearl River Estuary had obvious spatial agglomeration in recent 10 years, with the characteristics of high in the east and low in the west and aggregation and distribution towards the estuary. Specifically, in 2010, the overall level of synergetic development of the Pearl River port was relatively low. Except that Dongguan on the east coast was in the intermediate and advanced stage of symbiotic and synergetic development, other regions were in the intermediate stage of diffusion development. By 2015, Shenzhen entered the intermediate and advanced stage of symbiotic and synergetic development, and the other four cities were still in the stage of intermediate diffusion development. In 2019, Shenzhen on the east coast entered the advanced stage of integrated and synergetic development, Dongguan, Huizhou, Jiangmen and Zhuhai on the west coast entered the intermediate and advanced stage of symbiotic and synergetic development, and Zhongshan's synergetic development was still in the intermediate stage of diffusion development.

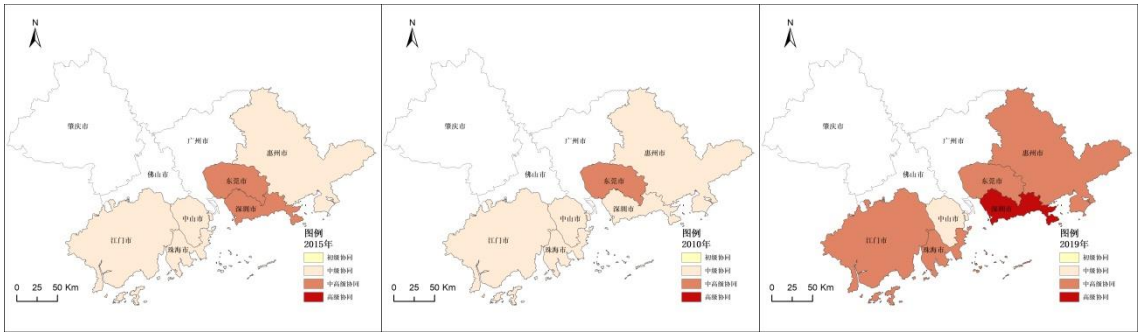

Figure 2 The spatial distribution of economic synergistic development of the east and west coasts of the Pearl River Estuary in 2010, 2015 and 2019.

4. CONCLUSION

This study analyzes the evolution trend and spatial distribution characteristics of the economic synergistic development of the east and west coasts of the Pearl River Estuary from 2010 to 2019, and draws the following conclusions:

From the perspective of synergetic development validity, the degree of economic synergistic development of the east and west coasts of the Pearl River Estuary from 2010 to 2019 was 0.51, indicating that it just entered the medium and advanced stage of symbiotic development and did not reach the DEA validity. From a regional perspective, the degree of regional economic synergetic development on the east coast was higher than that on the west coast, with the highest in Shenzhen and the lowest in Zhongshan.

From the perspective of development and evolution trend, the economic synergistic development of the east and west coasts of the Pearl River Estuary has shown an overall upward trend in recent 10 years, with slight fluctuations in individual years, and the rising rate of synergistic development level is 46.8%. The evolution trend of the comprehensive validity of the economic synergistic development of various cities is basically consistent with that of the east and west coasts of the Pearl River Estuary. Shenzhen has the largest increase, and the difference in the level of economic synergetic development of the east and west coasts shows an expanding trend.

From the perspective of spatial differentiation, the level of economic synergistic development of the east and west coasts of the Pearl River Estuary has obvious spatial agglomeration, which is characterized by high in the east and low in the west and aggregation towards the estuary.

It can be seen that the east and west coasts of the Pearl River Estuary have been promoted by a series of major policies and measures, such as the "outline of the development plan of Guangdong-Hong Kong-Macao Greater Bay Area" and "the outline of the development plan of the Pearl River Delta (2008 ~ 2020)", and the regional economic development has been increasingly coordinated. However, the overall level of regional economic synergistic development of the east and west coasts of the Pearl River Estuary is low, and the difference between the synergistic development of the east and west coasts is gradually widening. In the future, the east and west coasts of the Pearl River Estuary should continue to improve the mechanism for synergistic development under the guidence of "the Outline of the Development Plan for Guangdong-Hong Kong-Macao Greater Bay Area" and other policy documents. At the same time, it is suggested to strengthen the construction of rail transport and high-speed corridors on the east and west coasts of the Pearl River, realize the interconnection of the east and west coasts of the Pearl River, promote the flow of regional factors, form an industrial layout that matches the resource endowments of each city, narrow the economic gap between the two coasts, enhance the economic synergistic development of the west coast of the Pearl River Estuary, and continue to promote the economic synergetic development towards an advanced integration stage.

AUTHORS' CONTRIBUTIONS

This paper is independently completed by Longfang Chen.

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