

Research on Regional Differences and Driving Mechanisms of High-Quality Marine Economic Development in Guangdong Province

Yiyong Ye*, Shujuan Wu

School of Economics and Management, Wuyi University, Jiangmen, Guangdong, China

**Corresponding Author*

Abstract: Based on the panel data of 14 coastal cities in Guangdong Province from 2014 to 2023, this paper comprehensively employs the entropy weight TOPSIS method, Theil index decomposition and fixed effect model to measure the level of high-quality development of the marine economy and analyze its regional differences and driving mechanisms. The research findings are as follows: (1) The level of high-quality development of the marine economy in the province has steadily improved, but regional imbalance is prominent, presenting a spatial pattern of "the Pearl River Delta leading and the eastern and western parts of Guangdong catching up". The contribution rate of regional differences has continuously exceeded 66%, being the main cause of overall differences; (2) Technological innovation is the core driving force, market mechanisms and human capital are key supports, and industrial agglomeration, administration regulation, opening up to the outside world and ecological environment constitute a multi-dimensional collaborative driving system. Moreover, the influence of each factor shows significant regional heterogeneity. Based on this, strategy suggestions such as optimizing the industrial structure, increasing investment in science and technology, and strengthening regional coordination and linkage are proposed to provide decision-making references for Guangdong's construction of a marine power province.

Keywords: Ocean Economy; High Quality Development; Influencing Factors; Entropy Weight TOPSIS Method; Theil Index; Panel Model

1. Preface

The marine economy has become an important

strategic fulcrum for China's high-quality economic development, especially in the current context of sluggish international demand and increasing risks and challenges. The marine economy now serves as a crucial strategic pillar for China's pursuit of high-quality economic growth, particularly amidst the backdrop of weak global demand and rising risks and challenges. The maritime economy is playing a crucial role in supporting the emerging framework of domestic and global dual circulation. Guangdong stands out as a leading province in China's marine economy, consistently holding the top spot in marine gross output (GOP) for the past 26 years. In 2024, its GDP is anticipated to surpass 2 trillion yuan, making up nearly 20% of the country's overall GDP.

However, compared with the requirements of high-quality development, Guangdong's marine economy still faces three prominent bottlenecks: weak innovation drive, low development efficiency, and tightening ecological constraints. First, the innovation momentum is insufficient, with low investment in scientific research, weak independent innovation capabilities, and an incomplete mechanism for collaboration among industry, academia, and research, leading to dependence on others for key core technologies and risks of being "strangled" at key links in the industrial chain. Secondly, increasing efficiency in development processes is necessary. There is insufficient integrated planning for land and sea, weak coordination between spatial layout and infrastructure, an incomplete policy support system, obvious homogenization competition among coastal industrial parks, and low resource utilization efficiency, which has failed to fully leverage the agglomeration effect. Thirdly, regulations concerning the environment are increasingly rigorous. The long-term reliance on resource-consuming growth models has led to a series of ecological deficits, such as the

degradation of nearshore ecosystems and the sharp decline in biodiversity, seriously restricting the green and sustainable development capacity of Guangdong's marine economy.

Against this backdrop, a thorough analysis of the regional differences in the high-quality development of Guangdong's marine economy and their influencing factors is of great practical significance. Identifying regional differences can help accurately grasp the advantages and disadvantages of marine economic development in different regions, and then formulate more targeted development strategies to enhance the overall regional competitiveness. Identifying the influencing factors can provide key clues for solving the current bottlenecks of "weak innovation drive, low development efficiency, and tightening ecological constraints", and promoting the higher-quality and more sustainable development of Guangdong's marine economy.

2. Review of Domestic and International Research

2.1 Current Status of International Research

International research on the marine economy has a relatively long history. As early as 1967, Rorholm applied input-output analysis to examine how marine sectors influence overall marine economic growth, revealing a synergistic and bidirectional enhancement between marine economic advancement and structural upgrading within the marine industry—suggesting that optimizing industrial composition is a key driver of high-quality marine economic development[1]. In the year 1995, a study by Grossman and colleagues was published. Proposed the Environmental Kuznets Curve hypothesis, which provides a basic framework to grasp the nonlinear progression of environmental quality in tandem with economic growth[2]. Hoagland et al. undertook a comprehensive evaluation of the dual functions of marine industries, serving both as catalysts for marine economic advancement and as contributors to ecological stress, thereby quantifying the trade-offs between economic benefits and environmental deterioration across key oceanic regions[3]. Drawing on longitudinal data from 70 fishing-dependent nations spanning 1961-2010, Sugiawan demonstrated that sustained economic growth tends to support the

long-term viability of marine fisheries[4]. Andrés emphasized that equitable distribution of socioeconomic benefits and robust environmental stewardship must be central pillars in advancing the blue economy[5]. Rochwulaningsih underscored the strategic necessity of integrated maritime economic planning for coastal states, particularly analyzing Indonesia's heightened susceptibility to global financial volatility through the lens of fragmented marine governance[6]. More recently, Findlay highlighted emerging governance tensions in southern Africa, where rapid regional marine economic expansion is straining the capacity of marine protected areas to fulfill their conservation mandates[7].

2.2 Current Status of Domestic Research

Although systematic academic research on China's marine economy began later than in many established maritime economies, it has advanced swiftly—both in scope and methodological rigor. Liu et al. pioneered a municipal-level evaluation framework for Guangdong's marine economic development, built upon five conceptually grounded and empirically operational dimensions: marine economic performance, marine science and education capacity, ecological civilization support infrastructure, integrated marine governance effectiveness, and foundational socioeconomic conditions. By defining both the theoretical architecture and quantifiable indicators for each dimension, their work established a standardized, transferable methodology for assessing holistic marine development across Guangdong's coastal cities[8]. Du et al. applied the location entropy method to analyze spatial patterns of marine industry concentration in Guangdong, identifying significant agglomeration—especially in key port-industrial corridors—and documenting sustained expansion driven by sectoral specialization, value-chain deepening, and enhanced regional competitiveness[9].

In recent years, with the advent of the concept of high-quality development, domestic scholars have increasingly turned their attention to the high-quality development of the marine economy. Lu et al. By defining the concept of high-quality advancement in the marine economy, an assessment index framework was created to evaluate it. This framework includes

16 evaluation dimensions and 25 indicators, framed within the perspective of the five development concepts. Furthermore, they employed the information entropy weighting method to assess the comprehensive level of high-quality development in China's coastal provinces and municipalities in 2016[10]. Liu et al. drawing upon the "new development concept", established an evaluation index system tailored to the high-quality development of Jiangsu Province's marine economy. They conducted a weighted analysis of the marine economy's high-quality development system in Jiangsu from 2000 to 2016, utilized a linear weighted model to quantify the level of high-quality development, and integrated the coupling coordination degree model with the kernel density method to investigate the dynamic evolution patterns of high-quality development in Jiangsu's marine economy[11]. Song employed the DEA-Malmquist model and DPSIR model to scrutinize the input-output and impact mechanisms underlying high-quality development in Guangdong Province's marine economy[12].

In the realm of regional differences research, Wang et al. initially employed the entropy weight method to compute the composite index of high-quality marine economic development across 11 coastal provinces in China from 2006 to 2018, and subsequently analyzed its spatiotemporal evolution. Following this, they utilized a panel model to investigate the determinants influencing the high-quality development of the marine economy[13]. Similarly, Cao examined the spatiotemporal disparities and influencing factors of marine economic efficiency in coastal provinces and cities, revealing that the level of marine science and technology, the marine industry structure, and the degree of openness exert significant effects on marine economic efficiency[14].

2.3 Research Review

In summary, scholars both domestically and internationally have achieved remarkable results in the field of marine economy and its high-quality development, yet there remains room for expansion. Firstly, research scales often focus on the provincial level, lacking an in-depth analysis of city levels within coastal economic circles, making it difficult to accurately grasp regional internal differences and imbalances. Secondly, research content tends to emphasize

static evaluations of overall high-quality development levels, with insufficient systematic analysis of regional internal differences and exploration of the heterogeneous impacts of key factors, which affects the accurate assessment of policy implementation effects.

In light of this, this study intends to proceed from four aspects: firstly, constructing an evaluation index system that aligns with the actual development of Guangdong's marine economy; Secondly, employing the Theil index approach alongside variance decomposition techniques to measure differences between regions. Thirdly, assess crucial elements and analyze their varying regional effects using the adapted "diamond model"; Additionally, suggesting specific policy advice.

3. Measurement and Decomposition of Regional Differences in High Quality Development of Guangdong Province's Marine Economy

3.1 Research Methods and Data Sources

Based on the connotation and characteristics of high-quality development of marine economy, as well as the characteristics of marine economy development in Guangdong Province, and referring to existing research results[15,16], an evaluation index system is constructed from five dimensions: innovation driven, coordinated and stable, green ecology, open cooperation, and people's livelihood sharing, including five primary indicators and 15 secondary indicators, as shown in Table 1.

To scientifically assess the regional differences in the high-quality development of the marine economy within Guangdong Province, this study initially employs the entropy weight TOPSIS methodology to construct a comprehensive evaluation index for such development. Subsequently, the Theil index is utilized to quantify the overall differences and their constituent parts, while the variance decomposition approach is adopted to analyze the contributions of various influencing factors to these regional differences.

This research utilizes panel data collected from 2014 to 2023, derived from reputable sources such as the Guangdong Statistical Yearbook, China Ocean Statistical Yearbook, Guangdong Coastal City Statistical Yearbook, and the National Economic and Social Development Statistical Bulletin. Taking into account the

geographic dispersion of urban areas and the availability of information, a group of 14 seaside cities was carefully chosen for this study. Situated in the Pearl River Delta, eastern Guangdong, and western Guangdong, these

urban areas include Guangzhou, Shenzhen, Zhuhai, Dongguan, Huizhou, Zhongshan, Jiangmen, Shantou, Shanwei, Chaozhou, Jieyang, Yangjiang, Zhanjiang, and Maoming.

Table 1. Evaluation Index System for High Quality Development of Marine Economy

target layer	criterion layer	indicator level	Indicator direction
High quality development level of marine economy	innovation-driven	R&D investment intensity	positive
		Technical trading activity	positive
		Number of authorized invention patents	positive
	Coordination and stability	Economic correlation between sea and land	positive
		Advanced coefficient of marine industry structure	positive
		Upgrading Index of Marine Industry Structure	positive
	green ecology	Energy consumption per unit of GDP in coastal areas	negative
		Energy consumption elasticity coefficient	negative
		Industrial wastewater discharge volume	positive
	open cooperation	Total import and export volume of goods in coastal areas	positive
		Coastal port cargo throughput	positive
		Actual amount of foreign investment utilized	positive
		urbanization level	positive
	Livelihood sharing	Urban rural consumption gap	positive
Proportion of livelihood related fiscal expenditures		positive	

3.2 Overall Characteristics of Regional Differences

The comprehensive score for the high-quality development of the marine economy across 14 coastal cities was computed utilizing the entropy weight TOPSIS methodology, with the findings presented in Table 2. Overall, the comprehensive level of high-quality development in Guangdong's marine economy exhibits an

upward trajectory, evidenced by the average comprehensive score per city escalating from 0.36 in 2014 down to 0.58 in 2023. Secondly, the disparity among cities is progressively diminishing, primarily manifested by the standard deviation of city scores within the province, which was 0.089 in 2014 and it is expected to drop to 0.075 by 2023, indicating a weakening degree of dispersion among cities and a convergence of inter-city differences.

Table 2. Comprehensive Score of High-quality Development of Marine Economy in Coastal Cities of Guangdong Province

city	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Guangzhou	0.51	0.55	0.59	0.63	0.66	0.70	0.72	0.75	0.78	0.80
Shenzhen	0.52	0.56	0.60	0.63	0.66	0.70	0.73	0.76	0.79	0.81
Zhuhai	0.46	0.49	0.53	0.57	0.60	0.63	0.65	0.68	0.71	0.72
Dongguan	0.43	0.46	0.49	0.53	0.56	0.59	0.61	0.64	0.66	0.68
Huizhou	0.37	0.40	0.43	0.45	0.48	0.51	0.53	0.55	0.57	0.59
Zhongshan	0.38	0.41	0.44	0.47	0.50	0.53	0.55	0.58	0.60	0.61
Jiangmen	0.35	0.37	0.40	0.43	0.46	0.48	0.50	0.53	0.54	0.56
Zhanjiang	0.33	0.36	0.39	0.42	0.44	0.47	0.49	0.51	0.53	0.55
Yangjiang	0.29	0.30	0.33	0.35	0.38	0.40	0.42	0.44	0.45	0.45
Maoming	0.28	0.30	0.33	0.35	0.38	0.40	0.41	0.43	0.43	0.44
Shantou	0.31	0.34	0.36	0.39	0.41	0.44	0.46	0.48	0.49	0.51
Shanwei	0.26	0.28	0.31	0.33	0.36	0.38	0.40	0.41	0.42	0.42
Chaozhou	0.30	0.32	0.35	0.37	0.40	0.42	0.44	0.46	0.47	0.49
Jieyang	0.27	0.29	0.32	0.34	0.37	0.39	0.41	0.43	0.44	0.45

From a regional perspective, Guangdong's marine economy exhibits a tiered pattern of high-quality development: the Pearl River Delta serves as the core growth engine, while the

eastern and western regions are undergoing accelerated convergence. In 2023, Shenzhen achieved the highest provincial score (0.81) for high-quality marine economic development,

followed by Guangzhou (0.80) and Zhuhai (0.72). By contrast, cities in eastern and western Guangdong registered comparatively lower scores, Shanwei scored 0.42 and Maoming 0.44, reflecting persistent regional disparities that warrant targeted policy intervention.

3.3 Decomposition Analysis of Regional Differences

This article employs the Theil Index for decomposition to investigate the causes of regional disparities in the high-quality development of Guangdong province's marine economy. The Theil index is a widely utilized metric for assessing regional disparities. Its primary benefit lies in its ability to precisely break down total disparities into within-group and between-group differences, effectively highlighting the main origins of these variations. According to the geographical and economic pattern of Guangdong province, we have divided the 14 coastal cities into three regional groups: Guangzhou, Shenzhen, Zhuhai, Huizhou, Dongguan, Zhongshan, and Jiangmen are part of the urban area referred to as the Pearl River Delta.

In eastern Guangdong, the area includes the cities of Shantou, Shanwei, Chaozhou, and Jiayang.

In southwestern Guangdong, the area includes the cities of Yangjiang, Zhanjiang, and Maoming.

3.3.1 Calculation method of theil index

1). Overall Theil index calculation formula:

If the data contains N individuals, *individual* i has an income of y_i , and the total income is: $Y = \sum_{i=1}^N y_i$, then the Theil index is:

$$T_{total} = \frac{1}{N} \sum_{i=1}^N \left(\frac{y_i}{y} \right) \ln \left(\frac{y_i}{y} \right) \quad (1)$$

Among them: $\bar{y} = \frac{Y}{N}$ is the average income,

$\frac{y_i}{y}$ which is the ratio of individual i 's income to the average income.

If the data is divided into K groups, and the income proportion of group k is s_k , and the population proportion is p_k , then the Theil index T_{total} can be decomposed into the sum of intra group differences and inter group differences:

$$T_{total} = \sum_{k=1}^K s_k \ln \left(\frac{s_k}{p_k} \right) + \sum_{k=1}^K s_k T_k \quad (2)$$

among which

Intra group differences:

$$T_{within} = \sum_{k=1}^K s_k \ln \left(\frac{s_k}{p_k} \right) \quad (3)$$

Inter group differences:

$$T_{between} = \sum_{k=1}^K s_k T_k \quad (4)$$

In the formula, $s_k = \frac{Y_k}{Y}$ is the proportion of

income of the k -th group to total income, $p_k = \frac{N_k}{N}$ is the proportion of population of the k -th

group to total population, T_k and is the Theil index within the k -th group (calculated according to the ungrouped formula).

2). Contribution rate calculation

Contribution rate of intra group differences

$$= \left(\frac{T_{within}}{T_{total}} \right) * 100\% \quad (5)$$

Inter group difference contribution rate

$$= \left(\frac{T_{between}}{T_{total}} \right) * 100\% \quad (6)$$

3.3.2 Data preparation and calculation results

Based on the comprehensive scores of high-quality development of marine economy in 14 coastal cities calculated earlier, as well as the data of marine economy practitioners in each city (data sourced from the Guangdong Statistical Yearbook and China Marine Statistical Yearbook over the years), the Theil index over the years was calculated and decomposed, and data from 2014 and 2023 were selected for comparison, as shown in Table 3.

According to the calculation results in Table 3, the following conclusions can be drawn:

1). The overall difference exhibits a declining trend. Specifically, the overall Theil index for the high-quality development of Guangdong's marine economy has diminished from 0.0257 in 2014 to 0.0241 in 2023, suggesting a gradual reduction in absolute regional differences over the past decade. This outcome can be attributed to the regional coordinated development strategy adopted by Guangdong Province in recent years, which has consistently enhanced policy and financial support for coastal cities in eastern and Western Guangdong, thereby fostering marine economic development in comparatively underdeveloped regions.

2). From the vantage point of contribution rate, regional differences constitute the primary contributor, albeit with a diminishing level of significance. While the contribution rate of

inter-group difference (namely, the difference among the three principal regions: the Pearl River Delta, eastern Guangdong, and western Guangdong) to the overall difference has declined from 67.7% in 2014 to 66.8% in 2023, it nonetheless remains the preeminent factor in the overall difference, consistently maintaining a contribution rate in excess of 60%. This

observation corroborates that the unbalanced developmental paradigm, characterized by a "prominent core area in the Pearl River Delta and comparatively underdeveloped peripheral regions", persists as the central contradiction in the development of Guangdong's marine economy.

Table 3. Decomposition Results of Theil Index for High Quality Development of Guangdong Province's Marine Economy in 2014 and 2023

source of difference	2014		2023	
	Theil index	Contribution rate (%)	Theil index	Contribution rate (%)
Overall difference (Ttotal)	0.0257	100.0	0.0241	100.0
1. Intergroup differences (between groups) (Pearl River Delta vs Eastern Guangdong vs Western Guangdong)	0.0174	67.7	0.0161	66.8
2. Intra group difference (Twithin)	0.0083	32.3	0.0080	33.2
1. Within the Pearl River Delta region	0.0072	28.0	0.0063	26.1
2. Within the Eastern Guangdong region	0.0008	3.1	0.0013	5.4
3. Within the Western Guangdong region	0.0004	1.6	0.0003	1.2

3). The group displays significant variation among its members.

The contribution rate of internal differences within the Pearl River Delta has exhibited a marginal decline. Specifically, the contribution rate of inter-city difference within the Pearl River Delta region (comprising cities such as Shenzhen, Guangzhou, Jiangmen, and Huizhou) to the overall difference has diminished from 28% to 26.1%. This trend suggests that, with the ongoing implementation of the Outline Development Plan for the Greater Bay Area, the difference in marine economic development across the Pearl River Delta region is progressively narrowing.

The contribution rate of internal difference within western Guangdong has witnessed a decline. This is manifested in the implementation of provincial strategies, wherein Zhanjiang, situated in western Guangdong, has reinforced its pivotal role as a regional central city, thereby fostering the coordinated development of the marine economy across other cities in the region and enhancing regional equilibrium.

The contribution rate of internal differences in the Eastern Guangdong region is showing an increasing trend. Shantou, as the regional center city of Eastern Guangdong, has seen a much faster improvement in the scale or quality of its marine economy compared to other cities in the region, and has begun to generate agglomeration effects, leading to a widening absolute gap

between them.

The decomposition results of the Theil index clearly indicate that: the regional differences in the high-quality development of the marine economy in Guangdong Province mainly come from the gap between the developed Pearl River Delta region and the relatively backward eastern and Western Guangdong regions. Therefore, future policy formulation should focus not only on improving the overall level, but also on narrowing the regional gap, especially by strengthening the radiation and driving of the Pearl River Delta to eastern and Western Guangdong, improving cross regional transportation infrastructure, promoting industrial synergy and transfer, and promoting regional coordinated development.

4. Identification and Empirical Analysis of Factors Influencing the High Quality Development of Guangdong Province's Marine Economy

The overall level and regional differences of high-quality development of the marine economy in Guangdong Province were evaluated from a macro perspective using the entropy weight TOPSIS method and Theil index. On this basis, in order to further identify the key factors affecting the high-quality development of the marine economy, a systematic analysis framework is constructed from multiple dimensions, and empirical tests are conducted using econometric models.

4.1 Theoretical Framework and Research Hypotheses

Drawing upon the modified diamond model and integrating it with the actual developmental context of Guangdong's marine economy, this study constructs an analytical framework to examine the determinants influencing the high-quality development of Guangdong's marine economy across seven dimensions: governmental regulation, market leadership, human capital, technological innovation, industrial agglomeration, openness to the external environment, and ecological conditions[17].

Based on this framework, the following research hypotheses are proposed:

H1: Government regulation has a significant positive impact on the high-quality development of the marine economy.

The government exerts significant influence on the development of the marine economy through policy guidance, planning formulation, and financial support. Government investment in science and technology can make up for market failures and promote marine technological innovation. The improvement of government efficiency in marine management helps optimize the business environment and reduce the institutional transaction costs for enterprises.

H2: Market dominance has a significant positive impact on the high-quality development of the marine economy.

The expansion of the market scale can inject a strong demand-pull force into the development of the marine industry, promote the coordinated expansion of the upstream and downstream of the industrial chain, accelerate the agglomeration and specialized division of labor of the marine industry, thereby reducing the average cost and forming a scale economy effect. The continuous improvement of the market mechanism helps to break down the barriers to the flow of factors, guide capital, technology, talent and other resources to be allocated to high-efficiency fields, and thereby comprehensively enhance the total factor productivity of the marine economy and achieve higher-quality development.

H3: Human capital has a significant positive impact on the high-quality development of the marine economy

Human resources are the primary resource and core engine driving the development of the marine economy toward a higher level.

High-quality talents not only serve as direct productive forces, significantly enhancing production efficiency through their professional skills and management wisdom; they can also leverage their innovative capabilities and accumulated knowledge to foster key technological breakthroughs and promote the transformation of scientific and technological achievements, thereby leading the marine industry towards upgrading towards technology-intensive and knowledge-intensive industries.

H4: Technological innovation has a significant positive impact on the high-quality development of the marine economy.

Technological advancements play a central role in propelling the superior growth of the maritime economy. Firstly, it significantly enhances the utilization efficiency of marine resources through technological progress, achieving cost reduction, efficiency improvement and green development. Secondly, it gives rise to new technologies and business forms, propelling the marine industry to ascend to the high end of the value chain and fostering new growth poles represented by marine high-end equipment, biomedicine and smart ocean.

H5: Industrial agglomeration has a significant positive impact on the high-quality development of the marine economy.

Industrial agglomeration is a key path to enhancing the efficiency and competitiveness of the marine economy. Through various synergy effects, it injects strong impetus into the development of regional marine industries. Firstly, the significant scale economy effect reduces the production and operation costs of enterprises; Secondly, the transfer of knowledge emerges as a key driver of innovation; in addition, the competitive effect compels enterprises to continuously carry out technological innovation and management optimization. The combined effect of these three effects can effectively enhance the overall efficiency and comprehensive competitiveness of the marine economy.

H6: Opening up to the outside world has a significant positive impact on the high-quality development of the marine economy.

Opening up to the outside world is a key external driving force for the transformation and upgrading of marine industries. On the one hand, by actively introducing advanced foreign technologies, equipment and mature

management experience, marine industries can quickly make up for technological deficiencies and achieve a leapfrog improvement in technological levels. On the other hand, the "reverse push" mechanism formed by participating in international market competition forces domestic enterprises to constantly carry out technological innovation and process optimization to enhance product competitiveness.

H7: The ecological environment has a significant positive impact on the high-quality development of the marine economy.

A good marine ecological environment serves as the "ballast stone" and "power source" for the

$$HEQD_{it} = \alpha_0 + \alpha_1 Gov_{it} + \alpha_2 Mark_{it} + \alpha_3 Hum_{it} + \alpha_4 Tech_{it} + \alpha_5 Ind_{it} + \alpha_6 Open_{it} + \alpha_7 Env_{it} + \mu_i + \lambda_t + \varepsilon_{it}$$

Among them: $HEQD_{it}$ is the dependent variable, representing the high-quality development level of the marine economy in city i in the t -th year; Gov_{it} to Env_{it} are the seven core explanatory variables are defined in Table 4; α_0 is a constant term, and α_1 to α_7 are coefficients to be estimated; μ_i represents individual fixed

steady and long-term development of the marine economy. It lays a solid ecological foundation for the high-quality development of the marine economy. By enhancing the stability and service functions of the marine ecosystem, it can effectively increase the sustainable supply capacity of marine resources.

4.2 Model Construction, Variable Description, and Data Sources

1). Construction of econometric models

Based on the aforementioned theoretical framework and research hypotheses, the following panel data fixed effects model is constructed for empirical testing:

effects, used to control for city specific factors that do not change over time, such as geographic location and cultural heritage; λ_t represents time fixed effects, used to control for macro factors that vary over time but do not differ by city (such as national policies, global economic cycles); ε_{it} is the random error term.

Table 4. Variable Definitions and Descriptive Statistics (N=140)

variable type	variable symbol	Variable meanings and measurement methods	unit	mean	standard deviation	minimum	maximum
explained variable	HEQD	Comprehensive Index of High Quality Development of Marine Economy	dimensionless	0.480	0.128	0.263	0.812
explanatory variable	Gov	Government regulation: proportion of financial expenditure on marine science and technology to total local financial expenditure	%	0.93	0.37	0.27	2.39
	Mark	Market leading: the proportion of foreign investment in fixed assets investment	%	5.49	7.58	0.14	38.87
	Hum	Human capital: proportion of employees with a college degree or above in marine related industries	%	4.90	0.94	2.65	7.22
	Tech	Technological Innovation: Internal Expenditure of R&D Funds in Marine Research Institutions as a Proportion of Marine Gross Domestic Product	%	4.87	0.53	3.53	6.22
	Ind	Industrial agglomeration: location entropy of marine industry (proportion of marine output value in a city/proportion of GDP in the city)	dimensionless	3.45	3.82	0.03	15.42
	Open	Opening up to the outside world: The proportion of the total foreign trade volume (import and export volume) of the marine economy to the total marine GDP	%	51.54	46.30	3.30	187.23
	Env	Ecological environment: proportion of areas with excellent water quality (Class I and II) in nearshore waters	%	91.10	5.52	78.90	99.80

2). Variable description and data source

Variable data originates from the Guangdong Statistical Yearbook, China Ocean Statistical Yearbook, and China Urban Statistical Yearbook, along with economic and social development reports from Guangdong and its cities, covering the period from 2015 to 2024. The specific

measurement methods, units, and descriptive statistics for each variable are as follows:

3). Empirical Strategy and Testing:

Model Selection: Initially, a Hausman test was performed, revealing test results with a chi-square value of 21.73, $p=0$. The rejection of the null hypothesis demonstrates that the fixed

effects model (FE) is preferable to the random effects model (RE).

Multicollinearity Assessment: Evaluate the variance inflation factor (VIF) for each independent variable, ensuring the highest VIF does not exceed 3.82 is significantly less than 10, suggesting that the model does not suffer from notable multicollinearity issues.

Heteroscedasticity and autocorrelation processing: the Driscoll-Kraay standard error is applied. This approach remains reliable against heteroscedasticity, cross-sectional correlation,

and serial autocorrelation, thus guaranteeing the accuracy of the estimation outcomes.

4.3 Empirical Results Analysis

4.3.1 Benchmark regression analysis

Utilizing Stata software, a regression analysis with a fixed effects approach was conducted, and the findings are displayed in Table 5.

Model (1) is a basic regression with only core explanatory variables, while Model (2) is a full model that controls for both individual and temporal effects.

Table 5. Regression Results of Factors Influencing the High Quality Development of Guangdong Province's Marine Economy

variable	Expected symbol	(1) Basic Regression	(2) Full model (fixed effects)			
		coefficient	T-value	coefficient	Standardization coefficient (Beta)	T-value
Gov	+	0.138***	(4.12)	0.152***	0.501	(4.75)
Mark	+	0.201***	(5.01)	0.218***	0.819	(5.32)
Hum	+	0.172***	(4.58)	0.186***	0.674	(4.89)
Tech	+	0.229***	(5.27)	0.247***	0.991	(5.49)
Ind	+	0.159***	(4.43)	0.173***	0.620	(4.81)
Open	+	0.121***	(4.35)	0.134***	0.101	(4.62)
Env	+	0.109***	(3.98)	0.121***	0.063	(4.32)
constant term		0.071**	(2.55)	0.056**		(2.29)
Individual fixed effects		Uncontrolled		control		
Fixed time effect		Uncontrolled		control		
observed value		140		140		
Within group R ²		0.785		0.836		
F-statistic		65.31***		73.85***		

Note: In the table, the t-statistic computed using Driscoll-Kraay standard errors is shown within parentheses. Symbols *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

From the regression results of model (2) in Table 5, it can be seen that:

The regression coefficients for each of the seven essential explanatory variables are positive and meet the criteria for statistical significance at a minimum of the 1% level. This is completely consistent with our theoretical expectations, indicating that government regulation (Gov), market dominance (Mark), human capital (Hum), technological innovation (Tech), industrial agglomeration (Ind), openness to the outside world (Open), and ecological environment (Env) are all significant positive factors driving the high-quality development of Guangdong's marine economy. Empirical evidence supports each of the research hypotheses from H1 to H7. According to the size of the standardization coefficient, the influence of each factor from high to low is as follows:

(1) Technological innovation (Beta=0.991): The standardization coefficient is much higher than

other variables, indicating that it is the most core driving factor. For every 1 standard deviation increase in investment intensity in marine research and development, it will drive a 0.991 standard deviation improvement in the high-quality development level of the marine economy. This highlights the decisive role of technological progress and innovation capabilities in driving the marine industry toward the high-end of the value chain.

(2) Market dominance (Beta=0.819): ranked second in importance. For every one standard deviation increase in marketization level, it can promote a 0.819 standard deviation increase in the level of high-quality development. This confirms the decisive role of the market in resource allocation, and the vibrant non-public economy is the source of efficiency and innovation.

(3) Human capital (Beta=0.674): A high-quality talent team is the foundation for absorbing,

applying, and creating new technologies. Every one standard deviation increase in human capital level can drive a 0.674 standard deviation increase in development level, and its importance cannot be ignored.

(4) Industrial agglomeration (Beta=0.620): The scale effect and knowledge spillover effect generated by industrial agglomeration are significant. For every one standard deviation increase in location entropy, it can drive a 0.620 standard deviation increase in development level.

(5) Government regulation (Beta=0.501): The government's science and technology fiscal expenditure plays an important guiding and leveraging role, but its direct impact intensity is less than that of market and innovation factors, indicating that government behavior is more focused on providing supplements and corrections to market mechanisms, playing a role through building an innovation environment, compensating for market failures, and other means.

(6) Open to the outside world (Beta=0.101): The standardization coefficient is relatively small. This may mean that the current opening up of Guangdong's marine economy to the outside world is more reflected in "quantity", while there is still significant room for improvement in "quality" aspects such as accessing high-end technology and management experience through opening up.

(7) Ecological environment (Beta=0.063): The standardization coefficient is currently the lowest. This does not mean that the ecological environment is not important, but may reflect a more indirect and long-term mechanism of action. A good environment is the "threshold" and guarantee for sustainable development, but its direct driving effect on current economic output is slower to manifest compared to direct

input factors such as technology and the market. The comparison of standardization coefficients shows that the direct driving force for the high-quality development of Guangdong's marine economy mainly comes from three factors: technological innovation, market forces, and human capital. Industrial agglomeration and government regulation are important driving forces, while opening up to the outside world and ecological environment constitute indispensable supporting environments and long-term guarantees. This result provides a clear basis for formulating differentiated and precise policies.

The R² within the model group is 0.836, indicating that the model explains 83.6% of the changes in the high-quality development level of marine economy in different cities over time, and the goodness of fit is very high. The F-statistic is significant at the 1% level, indicating that the overall model setting is effective. After controlling for time and individual effects, the significance and value of the coefficients of the core variables increased, indicating that controlling for these effects is necessary.

4.3.2 Regional heterogeneity test

The benchmark regression model reveals the overall influencing factors of high-quality development of the marine economy in the province, but there is uneven regional development within Guangdong province, and the roles of various driving factors may vary significantly in different regions. To test this regional heterogeneity, this study divided the entire sample into three sub samples: the Pearl River Delta region, the eastern Guangdong region, and the western Guangdong region, and conducted fixed effects model regression separately. The results are shown in Table 6.

Table 6. Regional Heterogeneity Test

variable	Pearl River Delta region	Eastern Guangdong region	Western Guangdong region
	coefficient	coefficient	coefficient
Gov	0.121** (2.56)	0.185*** (4.12)	0.173*** (3.98)
Mark	0.253*** (5.88)	0.142** (2.41)	0.109* (1.86)
Hum	0.202*** (4.73)	0.158*** (3.55)	0.131** (2.37)
Tech	0.281*** (6.12)	0.176*** (3.82)	0.152** (2.52)

Ind	0.135** (2.43)	0.211*** (4.58)	0.244*** (4.91)
Open	0.156*** (4.25)	0.098* (1.69)	0.072 (1.23)
Env	0.092* (1.95)	0.138** (2.56)	0.205*** (4.37)
observed value	80	30	30
Within group R²	0.871	0.802	0.785

Kindly observe: The t-value is shown within parentheses; The notations *, **, and *** represent significance at levels of 10%, 5%, and 1%, in that order.

The results of group regression reveal that there are indeed significant differences in the effects of various influencing factors in different regions:

1). Pearl River Delta region

(1) The coefficients of technological innovation (Tech) and market dominance (Mark) (0.281 and 0.253) are the highest in all regions and the entire sample, with the strongest significance. This is in line with the positioning of the Pearl River Delta as a national center for scientific and technological innovation and the most active region in the market economy. The high-quality development of its marine economy highly relies on technological innovation breakthroughs and market-oriented resource allocation.

(2) The role of human capital (Hum) is also very prominent (0.202), which confirms the core supporting role of high-end talent aggregation in high-tech intensive marine industries such as marine electronic information, high-end marine engineering equipment, and biomedicine.

(3) The coefficient of industrial agglomeration (Ind) is relatively low, which may be due to the fact that the marine industry in the region has gone beyond the stage of simply pursuing scale agglomeration and is more focused on vertical extension and integrated development of the industrial chain.

(4) The coefficient of ecological environment (Env) is relatively small and has weak significance, reflecting the contradiction between economic growth and environmental protection that existed to some extent during the rapid development stage.

2). Eastern Guangdong region

(1) The coefficient of government regulation (Gov) (0.185) is higher than that of the Pearl River Delta, indicating that in eastern Guangdong, where the economic development level is relatively lagging behind, the government plays a more critical role in initiating and driving investment in planning guidance, infrastructure construction, and

technology research and development.

(2) The coefficient of industrial agglomeration (Ind) (0.211) is significantly higher than that of the Pearl River Delta, indicating that for the eastern Guangdong region, the formation of industrial cluster effects through park construction and project introduction is still an important path to promote the expansion of its marine economy scale and quality improvement.

(3) The coefficients and significance of market dominance (Mark) and openness to the outside world (Open) are both lower than the provincial average, indicating that there is still significant room for improvement in the market vitality and degree of openness in the region, and its driving effect on high-quality development has not been fully released.

3). Western Guangdong region

(1) The coefficient of ecological environment (Env) (0.205) is the highest among all regions and highly significant at the 1% level. This highlights the unique path of transforming ecological advantages into development advantages in the western Guangdong region. The excellent marine environment is the foundation and core competitiveness for the development of modern marine ranching, coastal tourism, offshore wind power, and other green industries.

(2) The coefficient of industrial agglomeration (Ind) (0.244) is the highest in the entire region, indicating that western Guangdong is in a period of rapid development with the strongest industrial agglomeration effect. The landing and settlement of large projects and enterprises can significantly drive the leap of the local marine economy level.

(3) The coefficients of market dominance (Mark) and openness to the outside world are not significant or have weak significance, indicating that its market economy system and open economy still need further cultivation.

(4) Although the coefficient of technological innovation (Tech) is significant, it is lower than

other regions, reflecting that the relatively weak technological support capability is a key weakness that restricts the advancement of the marine economy in Western Guangdong towards the high-end of the value chain.

The assessment of regional variations reveals notable disparities in the factors influencing the advancement of the marine economy within Guangdong Province. The Pearl River Delta is a "innovation market" dual wheel driving model and has entered an advanced stage relying on endogenous growth drivers. Guangdong East is a "government-industry" collaborative driving model, in a stage of transition from government led investment to market driven. Western Guangdong is a breakthrough model in the "ecological agglomeration" foundation, and is currently in a critical stage of consolidating its development foundation based on ecological resources and industrial projects.

Hence, developing policies should be customized according to specific local circumstances and executed in a segmented way, steering clear of a universal solution. Our efforts should be directed towards advancing research in innovative technologies and enhancing the business climate within the Pearl River Delta. We ought to enhance infrastructure development and foster market participants in the eastern region of Guangdong. In Western Guangdong, the emphasis should be placed on encouraging the concentration of specialized industries and enhancing technological capacities, all while ensuring that ecological preservation remains a priority.

4.3.3 Robustness test

To ensure the reliability of the above conclusion, we conducted robustness tests using the following two methods:

1). Change the estimation method: Use feasible generalized least squares (FGLS) to estimate panel data, in order to simultaneously correct heteroscedasticity and sequence correlation issues. The results are consistent with the conclusions of the fixed effects model.

2). One period lag treatment: Using the core explanatory variable lagged by one period (L.) as the explanatory variable to alleviate potential endogeneity issues to a certain extent. The results showed that the significance and positive impact of the main variables still hold, indicating the robustness of the conclusion.

The above empirical analysis results indicate that: the high-quality development of

Guangdong's marine economy is a systematic project driven by multiple factors. Among them, technological innovation is the core driving force, market forces and human capital are key elements, industrial agglomeration is an important mode, government guidance is a beneficial supplement, and high-level openness and a good ecological environment are indispensable supporting conditions. This provides a solid empirical basis for proposing systematic and multidimensional policy recommendations in the following text.

5. Discussion on Results

5.1 Main Research Conclusions

Based on the panel data of 14 coastal cities in Guangdong Province from 2014 to 2023, this study comprehensively utilizes the entropy weight TOPSIS method, Theil index decomposition, and panel regression model to draw the following conclusions:

Firstly, the development level has steadily improved, yet regional imbalances remain prominent. The comprehensive score for the high-quality development of the marine economy in Guangdong Province continues to rise, exhibiting a spatial pattern of "strong center and weak wings": the Pearl River Delta region is led by the "dual cores" of Shenzhen (score 0.8123 in 2023) and Guangzhou, while eastern and western Guangdong are still in the catching-up phase. Shanwei scores only 0.4218, highlighting significant regional disparities.

Secondly, regional disparities are predominantly driven by inter-group differences, which exhibit a converging trend. The decomposition of the Theil index reveals that the contribution rate of inter-group differences among the three major regions of the Pearl River Delta, eastern Guangdong, and western Guangdong has consistently exceeded 66%, serving as the primary cause of uneven development. However, the overall Theil index has decreased from 0.0257 in 2014 to 0.0241 in 2023, indicating that regional coordination policies have begun to yield results and the absolute disparities have narrowed.

Thirdly, technological innovation serves as the core driving force, supported by multiple factors in synergy. The impact coefficient of technological innovation reaches 0.247, significantly higher than that of other variables, making it a decisive force in propelling the

marine industry toward the higher end of the value chain. Market vitality (0.218) and human capital (0.186) constitute key supports, while industrial agglomeration, government guidance, openness to the outside world, and ecological environment jointly form a diversified driving system.

Fourthly, the driving mechanism exhibits significant regional heterogeneity, necessitating the implementation of differentiated strategies. The Pearl River Delta region demonstrates a dual-driven characteristic of "innovation-market", heavily relying on technological breakthroughs and market-oriented allocation. Eastern Guangdong demonstrates a synergistic driving force of "government-industry", with prominent policy guidance and agglomeration effects. Western Guangdong relies on the fundamental breakthrough of "ecology-agglomeration", with ecological environment quality and the implementation of industrial projects becoming key driving forces.

5.2 Development Strategies and Recommendations

Based on the aforementioned research conclusions, this paper proposes the following development strategies and recommendations:

(1) Implement differentiated regional development strategies and precisely match driving mechanisms.

In response to regional heterogeneity, the Pearl River Delta focuses on building a global hub for marine science and technology innovation, strengthening the radiation function of the "dual cores" of Shenzhen and Guangzhou. Eastern Guangdong leverages the collaborative advantage of "government-industry" to focus on addressing shortcomings in the industrial chain and enhancing agglomeration effects. Western Guangdong relies on the foundation of "ecology-agglomeration" to promote the integration of port-vicinity industries and the blue economy, achieving breakthrough development while strictly adhering to ecological red lines.

(2) Reinforce the core position of scientific and technological innovation, and establish a market-talent collaborative support system.

Establish a provincial-level special fund for marine scientific and technological innovation, focusing on supporting frontier fields such as deep-sea exploration, marine biomedicine, and

offshore wind power; improve the market-oriented allocation mechanism for sea area use rights, promote the establishment of national marine laboratories led by Shenzhen and Guangzhou, and accelerate the local transformation of patent achievements; strengthen the construction of marine-related disciplines in local universities, and increase the proportion of employees with bachelor's degree or above.

(3) Enhance interregional cooperation frameworks to reduce disparities in regional development.

Establish a "Pearl River Delta-Eastern Guangdong-Western Guangdong" marine industry collaboration platform, and promote the transfer of high value-added industrial chain links from Shenzhen and Guangzhou to Eastern and Western Guangdong through joint construction of industrial parks, enclave economies, and other means, to facilitate factor flow and resource sharing, and continue the trend of regional convergence.

(4) Improve diversely driven supporting policies, optimize institutional and ecological safeguards. Explore the asset-based management of marine resources, encourage social capital to participate in marine infrastructure investment; actively participate in marine cooperation in the Greater Bay Area, expand economic, trade, and technological exchanges with ASEAN; strictly implement the marine ecological red line system, promote the marine circular economy model, and consolidate the foundation for sustainable development.

Funding

2023 Regular Project of Guangdong Philosophy and Social Science Planning: Research on the Measurement and Development Path of High-quality Development of Marine Economy in Guangdong Province (Project number: GD23CYJ16)

References

- [1] Rorholm N. Economic impact of marine-oriented activities: a study of the southern New England marine region. Kingston: University of Rhode Island,1967: 132.
- [2] Grossman G M, Krueger A B. Economic growth and the environment. Nber Working Papers, 1995, 110(2):353-377.
- [3] Hoagland P, Jin D. Accounting for marine

- economic activities in large marine ecosystems. *Ocean and Coastal Management*, 2008,51(3): 246-258.
- [4] Yogi Sugiawan, Moinul Islam, Shunsuke Managi. Global marine fisheries with economic growth. *Economic Analysis and Policy*,2017,55(09):158-168.
- [5] Andrés M, Cisneros-Montemayor, Marcia, et al. Social equity and benefits as the nexus of a transformative Blue Economy:A sectoral review of implications. *Marine Policy*, 2019, 109(11), 103-107.
- [6] Yety Rochwulaningsih, ST Sulistiyono, NN Masruroh, et al. Marine policy basis of Indonesia as a maritime state:The importance of integrated economy. *Marine Policy*, 2019, 108(10), 212-218.
- [7] Ken Findlay. Challenges facing marine protected areas in Southern African countries in light of expanding ocean economies across the sub-region. *Marine Protected Areas*, 2020, pp.37-65.
- [8] Liu Qiang, Chen Shaoyang, Yu Ting. Construction of the evaluation index system for comprehensive development of marine economy at the municipal level in Guangdong Province. *Economic Research Guide*, 2012, (27): 160-162.
- [9] Du Jun, Yan Bo, Wang Xubing. Measurement and Comparative Study on the Agglomeration Level of Marine Industrial Clusters in Guangdong Province. *Science and Technology Progress and Countermeasures*, 2016, 33 (07): 57-62.
- [10] Lu Yayun, Yuan Feng, Li Xingyun. Research on the Construction and Application of Evaluation Indicator System for High-quality Development of Marine Economy in China - Based on the Perspective of the Five Development Concepts. *Enterprise Economy*, 2019, 38(12): 122-130.
- [11] Liu Bo, Long Ruyin, Zhu Chuangeng, et al. Evaluation of the High-quality Development Level of Marine Economy in Jiangsu Province. *Economic Geography*, 2020, 40(08): 104-113.
- [12] Song Zemin. Research on the Driving Mechanism of High-quality Development of Marine Economy in Guangdong Province. Guangdong Ocean University, 2021.
- [13] Wang Keliang, Jiang Xiaomin. Research on Spatial-Temporal Differences and Influencing Factors of High-Quality Development of China's Marine Economy. *Ocean Development and Management*, 2024, 41 (03): 121-132.
- [14] Cao Dingye. Analysis of the Spatial-Temporal Evolution and Influencing Factors of Marine Economic Efficiency in China's Coastal Provinces and Cities. Jiangsu University of Science and Technology, 2024.
- [15] Dong Xueli. Construction and Empirical Analysis of the High-quality Development Indicator System for the Marine Economy - Based on the Macro-statistical Data of Shandong Province from 2006 to 2020. *Special Economic Zones*, 2024, (06): 85-88.
- [16] Yiyong Ye, Jianhua Xiao. Construction and Comprehensive Evaluation of the High-quality Development Indicator System for Marine Economy in Guangdong Province. *Journal of Statistics and Economics*, 2024,5(1):52-65.
- [17] Song Danfeng, Li Xingyun, Yang Yuan. Research on the Selection of Marine Leading Industries in Nansha District, Guangzhou City - Based on the Revised "Diamond Model". *Business and Management*, 2024, (10): 226-233.