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Dual advancement of marine economic growth and environmental governance: an empirical analysis of China's Marine Economic Development Pilot Zones

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Introduction: This research aims to empirically investigate the dual effects of establishing the Marine Economic Development Pilot Zone (MEDPZ) on marine economic growth and environmental governance. The study focuses on China's coastal provinces, where MEDPZs have been implemented, to assess their impacts on both economic and environmental aspects.

Methods: The study employs a Time-varying difference-in-differences (DID) model based on panel data from China's coastal provinces. This method allows for assessing the causal impact of MEDPZ establishment on marine economic growth and environmental governance by comparing pilot provinces with non-pilot provinces over time.

Results: The establishment of MEDPZ has significantly enhanced marine economic growth and environmental governance in the pilot provinces. Specifically, marine economic growth increased by 1.222 percentage points, while environmental governance improved by 0.748. Additionally, the impact of MEDPZ establishment varied spatially across different marine economic circles. The northern marine economic circle experienced the most substantial economic growth and environmental governance benefits. The southern marine economic circle saw a significant increase in economic growth but a relatively minor improvement in environmental governance. In contrast, the eastern marine economic circle was not substantially affected.

Discussion: The findings suggest that the establishment of MEDPZ has effectively boosted the competitiveness of the marine economy in pilot provinces while mitigating adverse environmental impacts. This is achieved through promoting scientific and technological advancement and strengthening government

regulation. The study provides a scientific basis for policymakers to formulate and implement marine economic development strategies that consider regional differences, enhance financial support for marine science and technology R&D, and enforce stricter regulations for marine environmental protection.

KEYWORDS

Marine Economic Development Pilot Zones, time-varying difference-in-differences model, marine economic growth, marine environmental governance, spatial heterogeneity

1 Introduction

The marine economy plays a vital role in global economic development, and the exploitation of marine resources and the protection of the marine ecological environment have become focal points of global attention. In recent years, China has established Marine Economic Development Pilot Zones (MEDPZ) to explore new models for the sustainable development of the marine economy and to promote the coordinated development of marine economic growth and environmental governance. The establishment of MEDPZ represents an innovation in marine economic policies and a significant measure for the construction of marine ecological civilization.

In recent years, the concept of the Blue Economy has gained traction as a comprehensive approach to sustainable marine development. The Blue Economy emphasizes the integration of economic growth, social equity, and environmental sustainability in the use and management of marine resources. It encompasses various activities, from traditional fisheries and shipping to emerging sectors such as marine renewable energy and blue biotechnology (Sarangi, 2023; Inbakandan, 2023). For example, the European Commission's report on the Blue Economy (2023) provides an overview of the evolution of blue economy sectors and their potential for future growth, emphasizing the need for sustainable development (Borriello et al., 2023). Complementing the Blue Economy, the Ocean Pact is a global initiative aimed at protecting and restoring the health of the world's oceans. The Ocean Pact reduces marine pollution, protects biodiversity, and promotes sustainable ocean governance. It involves collaborative efforts among governments, businesses, and civil society to address the marine environment's pressing challenges (Johnson et al., 2022). These new concepts provide a broader framework for understanding the dual advancement of marine economic growth and environmental governance, which is the focus of this study. By examining the establishment of MEDPZ through the lens of the Blue Economy and the Ocean Pact, we aim to offer a more comprehensive and forward-looking perspective on the sustainable development of China's marine economy.

The development of China's marine economy is of great significance to maintaining the country's economic security, promoting regional economic cooperation, and realizing sustainable development, as the country is endowed with vast sea areas and abundant marine resources (James et al., 2021; Kong et al., 2024). The State Council of China, in the "14th Five-Year Plan for the Development of Marine Economy", explicitly underscores the necessity of optimizing the spatial configuration of the marine economy, expediting the establishment of a modern marine industrial framework, augmenting the autonomous innovation capabilities in marine science and technology, harmonizing the conservation and development of marine resources, and protecting and extending the nation's maritime rights and interests. The Plan demonstrates China's heightened focus on the sustainable growth of the maritime economy (SCC, 2021). Meanwhile, In the "14th Five-Year Plan for the Marine Ecological and Environmental Protection", the State Council established explicit objectives, tasks, and measures for safeguarding the marine ecological environment, which encompasses enhancing the delineation and management of protective boundaries, advancing the restoration of marine ecosystems, and augmenting the capacity for monitoring and supervising the marine environment. This policy document indicates the government's prioritization of marine environmental protection and commitment to the sustainable development and ongoing enhancement of the marine ecological environment through legal, planning, and scientific and technological means (MEE, 2022). To attain synergistic advancement of the marine economy and the environment, China has instituted Marine Economic Development Pilot Zones (MEDPZ) in several provinces since 2010, aiming to enhance marine economic growth and reinforce marine environmental governance through policy innovation and regional collaboration (Fang et al., 2024). These policies and practices illustrate China's relentless efforts to accomplish the sustainable and coordinated growth of the regional marine economy and the environment. Consequently, The establishment of MEDPZ is an exemplary initiative for executing marine-related policies and advancing the sustainable growth of the ocean economy.

In the field of marine economy, Du and Han (2016) explore the fundamental theoretical issues of marine economics, systematically elucidate the nature of the discipline, its research object, and its content, and establish a strong theoretical foundation for a

comprehensive understanding of the marine economy in the context of marine economic growth. Cisneros et al. (2021) delineates the necessary conditions for the establishment of a sustainable marine economy from the perspectives of strategic investment and research direction. She underscores the interdependence of economic viability, environmental sustainability, and social justice. Wang et al. (2023) offer a valuable perspective on the research frontiers and knowledge structure of the marine field by conducting a systematic review of the current research status, development trends, and future orientations of the marine economy. In quantitative research, Ji et al. (2024) demonstrate the important role of the marine economy in the high-quality development of China's littoral economy. Wang H. et al. (2024) investigate the influence of the marine economy's growth on the economic stability of China's coastal regions from the standpoint of economic resilience. This study offers a novel theoretical perspective on the marine economy's role in the regional economy's development. Luo et al. (2020) have developed a multidimensional, high-quality development model of China's marine economy that analyzes the synergistic evolutionary conditions of the marine economy from the three dimensions of industry, region, and factors. This model provides a new analytical framework for the high-quality development of the marine economy.

In the field of marine environmental governance, Stojanovic and Gee (2020) evaluated the efficacy of marine environmental planning, highlighting the critical role of governance mechanisms in the preservation of marine environments. The significance of comprehending the interactions between governance and the environment and the linkages between agents within the environmental governance system was underscored by the study conducted by Dutra et al. (2019) in order to facilitate successful governance transitions. Mahon and Fanning (2019) underscore the indispensable nature of regional marine environmental governance in the pursuit of sustainable development objectives. It also examines the mechanisms of integration and coordination within regional governance clusters, identifying both the successes and obstacles associated with the successful implementation of regional integration in various regions.

Existing research primarily focuses on the theoretical elaboration and practical summary of MEDPZ policies. For instance, Sun et al. employed policy quantification and network analysis to explore the local dynamics of China's marine economic policies, revealing significant spatial and temporal variations in policy implementation (Sun et al., 2024). Huang and Liu analyzed the distribution of literature information in China's marine economic development demonstration zones using a network map, providing insights into the regional heterogeneity of MEDPZ policies (Huang and Liu, 2022). Moreover, Cui et al. (2024) evaluated the impact of MEDPZ policies on optimizing the marine industrial structure, using Zhejiang Province as a case study. Their findings indicated that MEDPZ policies significantly promoted optimizing the marine industrial structure, particularly in marine engineering equipment manufacturing and marine biotechnology. This study offers empirical evidence for understanding the specific pathways through which MEDPZ policies contribute to marine economic growth (Cui et al., 2024). Additionally, Ren et al. utilized a quasi-natural experiment approach to assess the impact of marine ecological civilization demonstration zone policies on the green development level of China's marine economy. Their research demonstrated that these policies significantly enhanced the green development level of the marine economy, especially in reducing pollution and improving resource utilization efficiency. This study provides important references for understanding the impact of MEDPZ policies on environmental governance (Ren et al., 2024). Despite these advancements, existing research still has limitations. Most studies focus on the macro-level marine economy and industrial structure, lacking a systematic assessment of the implementation effects of marine policies. Existing research is predominantly qualitative, with no long-term, systematic empirical studies. Moreover, exploring the impact pathways of MEDPZ policies is insufficient, and a comprehensive evaluation of policy implementation effects is lacking.

Consequently, This study aims to fill these gaps by employing a time-varying difference-in-differences (DID) model to systematically evaluate the dual impacts of MEDPZ policies on marine economic growth and environmental governance. Furthermore, this study explores the regional heterogeneity and mechanisms of policy impacts, providing a scientific basis for formulating marine economic policies.

This study contributes to three primary domains:

1. This study employs the Time-varying difference-in-differences (DID) model, which effectively estimates the impacts of the MEDPZ policy at various temporal periods. In contrast to the conventional DID model, the Time-varying DID model considers the temporal variation of policy impacts, offering a more precise approach to evaluating policy impact.
2. This study examines the variability of marine economic circles in northern, eastern, and southern China, elucidating various locations' distinct requirements and reactions regarding economic growth and environmental governance. This discovery establishes a robust foundation for developing regionally tailored policies that facilitate the integration of regional marine economic and environmental governance.
3. This study uses mechanism analysis to validate further how the establishment of the MEDPZ fulfills its goals by impacting key drivers, offering fresh insights into the transmission pathways and possible policy moderators.

The subsequent section of this study will explore the dual advancement of the MEDPZ in fostering the expansion of the marine economy growth and environmental governance in coastal provinces. The second section, "Theoretical Analysis," will provide a more detailed explanation of the theoretical foundation and assumptions of the study, which include the theory of benchmarking, heterogeneity, and impact mechanism. The third

section, "Data and Variables," will provide an overview of the study area, data sources, variable definitions, and model construction. The benchmark test, heterogeneity test, and mechanism test results will be presented in Section IV. The study findings will be summarized in Section V, which will also offer targeted policy recommendations. Finally, Section VI will discuss the study's limitations and suggest future research directions.

2 Theoretical analysis

2.1 Theory and assumption of the benchmark model

The theory of competitive advantage highlights the capacity of regions to develop advantages in specific sectors (Stonehouse and Snowdon, 2007). In the context of the marine economy, policy plays a crucial role in establishing conditions that encourage coastal pilot provinces to cultivate competitive advantages in the utilization of marine resources and major marine and associated industrial economic activity (Ji et al., 2024). By providing financial resources, the government has improved the competitiveness and flexibility of the area. As a result, the region has achieved a substantial edge in the national marine economic landscape (Kedong et al., 2022). As an example, the government may specifically endorse burgeoning sectors like marine biotechnology and marine energy. These businesses not only provide distinct competitive benefits to the pilot zones but also stimulate substantial macroeconomic expansion. Meanwhile, the government has successfully lured marine-related high-tech firms and research institutions to the clusters by using policy instruments like as tax incentives and R&D funding (Hu et al., 2022). The interconnections and collaborations among the companies in the cluster result in a substantial decrease in production expenses and enhance operational effectiveness. This gives the area a remarkable advantage in the worldwide market (Narayanan et al., 2023).

According to the theory of environmental management and governance, the pilot zones have facilitated the participation of a variety of actors in the governance of the marine environment, such as the government, enterprises, non-governmental organizations, and the public (Gao et al., 2024). Resource integration and information sharing are facilitated by this participatory mechanism, which significantly enhances the efficacy and effectiveness of governance (Djoumessi et al., 2019). By establishing a multi-party consortium to jointly oversee marine public affairs and implementing a multi-centered, highly participatory management model, it will be feasible to achieve a significant increase in the efficiency of marine environmental governance (Chen et al., 2021). Simultaneously, the pilot zones have implemented a variety of policy measures, including ecological compensation, tax incentives, and green credits, to continually enhance the watershed synergy mechanism for marine pollution prevention and control and deepen the integrated management of provincial watersheds in order to foster the continuous improvement and restoration of the marine ecological environment (Wang H. et al., 2024).

In conclusion, the establishment of MEDPZ offers substantial benefits by fostering the involvement of numerous stakeholders, enacting policy incentives, and fortifying the development of laws and regulations.

Consequently, this research suggests Hypothesis 1: The establishment of MEDPZ enhances marine economic growth and environmental governance in pilot provinces.

2.2 Theory and assumption of the heterogeneity

2.2.1 Theoretical foundation

The theory of comparative advantage offers a comprehensive explanation for why various areas prioritize their comparatively more effective economic activity (Costinot and Donaldson, 2012; Ruffin, 2002). This research examines the competitive advantages of the northern, eastern, and southern areas of coastal China in prompting the marine economy growth and environmental governance based on this theory.

The northern marine economic circle, which is distinguished by its mature heavy industrial base and abundant marine resources, possesses substantial comparative advantages, particularly in the fabrication of offshore engineering apparatus and shipbuilding. The production of offshore engineering apparatus is supported by a robust industrial foundation in Liaoning and Shandong, which are significant shipbuilding centers in China. Furthermore, the region's geographic location is opportune and facilitates access to both domestic and international markets due to its proximity to the metropolitan area and other countries in Northeast Asia. The region focuses on promoting technological innovation and industrial upgrading, aiming to maintain and strengthen its competitiveness in the global shipbuilding and offshore engineering sectors. Nevertheless, the development model, which is heavily reliant on port logistics and heavy industry, has also resulted in substantial industrial pollution issues. The MEDPZ is being established to aid in the region's transition to more environmentally favorable production methods. Its objective is to promote the implementation of marine environmental management projects and to alleviate the environmental burden on the port and transportation industry by implementing more stringent environmental standards and technological innovations.

The eastern marine economic circle, particularly Shanghai, is renowned for its highly developed financial market and service industry. It inherently provides a competitive edge for service-oriented sectors like marine finance and marine insurance. Jiangsu and Zhejiang, due to their well-established manufacturing and commerce sectors, are very conducive to the growth of marine biotechnology, marine medicines, and seafood processing businesses. The marine economies of these provinces provide robust support for seafood commerce due to their superior logistics and port infrastructure. The establishment of MEDPZ is

focused on enhancing the service and high-tech sectors in these areas and facilitating the advancement of the marine economy towards greater value-added activities. The eastern marine economic circle has developed a more profound appreciation for environmental protection as a result of the highly developed marine finance industry. Consequently, it may prioritize the sustainability of the marine economy and the environmental governance during the construction of the pilot area.

The southern marine economic circle has significant potential for the development of marine tourism and marine biotechnology due to its distinctive climatic conditions and abundant marine biodiversity. The economy of Guangdong and Fujian provinces is mostly based on the fishing industry and the processing of seafood. In contrast, Hainan province, with its distinctive tropical environment and picturesque coastline, has emerged as a popular destination for marine tourism. The coral reefs and biological resources in this area provide significant importance for biotechnology and pharmaceutical research. The establishment of the MEDPZ aims to use its inherent natural and geographical benefits in order to mitigate coastal erosion, marine pollution, and overfishing. This initiative serves to save regional biodiversity and stimulate tourism.

2.2.2 Heterogeneity analysis-case presentation

2.2.2.1 Northern Marine Economic Circle-Liaoning Province

Background: Liaoning is a significant province within China's northern marine economic circle, boasting abundant marine resources and a robust industrial base. It holds a notable advantage in marine engineering equipment manufacturing and shipbuilding. However, traditional marine industries account for a large proportion, while emerging marine industries lag. The total factor productivity (TFP) contribution rate of the marine economy is relatively low, with negative values in some years.

Policy Implementation and Achievements: Industrial Upgrading: Liaoning has established marine economic development pilot projects, investing heavily in marine infrastructure construction to promote the development of emerging industries such as marine engineering equipment manufacturing. After the implementation of these pilot projects, the input of marine economic factors has increased, driving the growth of the marine economy. Liaoning has strengthened marine ecological environment protection, guiding and financially supporting the green transformation of marine industries to reduce marine pollution and enhance the sustainable use of marine resources.

Challenges Faced: The large proportion of traditional marine industries and the relatively slow development of emerging marine industries make it challenging to adjust the industrial structure, which is constrained by funding and technological bottlenecks. Implementing strict environmental standards requires enterprises to invest substantial funds in equipment upgrades, increasing their burden.

2.2.2.2 Eastern Marine Economic Circle-Zhejiang Province

Background: Zhejiang Province is a significant player in China's eastern marine economic circle, with a highly developed marine economy. It holds notable advantages in marine finance and marine biotechnology industries. The high total factor productivity (TFP) contribution rate of Zhejiang's marine economy is closely related to the province's policy support in marine research, marine industries, and marine ecological environment protection.

Policy Implementation and Achievements: Zhejiang has promoted the development of marine finance and marine biotechnology industries through policy support, driving the growth of the marine economy. For example, the province has vigorously developed marine financial products and supported the innovation and development of marine biotechnology enterprises. Zhejiang has strengthened the protection of the marine ecological environment by implementing ecological compensation mechanisms and strict environmental supervision, promoting the green development of marine industries.

Challenges Faced: The development of marine financial products requires complex financial innovation and faces technological bottlenecks. Additionally, Marine ecological protection projects require substantial funding, but local fiscal pressure is significant.

2.2.2.3 Southern Marine Economic Circle-Guangdong Province

Background: Guangdong is the core province of China's southern marine economic circle, with a significant advantage in the total volume of the marine economy. In 2023, the marine gross product reached 3,572.7 billion yuan, accounting for 36.1% of the national marine gross product. The marine industrial structure of Guangdong is relatively optimized, with the rapid development of marine service industries and marine high-tech industries, especially in marine tourism and marine transportation.

Policy Implementation and Achievements: Guangdong has promoted the development of marine service industries and high-tech industries through policy support, driving the rapid growth of the marine economy. For example, Guangdong has developed a number of high-end marine tourism projects, attracting a large number of domestic and foreign tourists. Guangdong has implemented strict environmental supervision and promoted the implementation of marine ecological protection projects to protect marine biodiversity. For example, Guangdong has achieved significant results in seawater desalination and comprehensive utilization, with the added value of this industry accounting for 39% of the national total in 2023.

Challenges Faced: The rapid development of the marine economy has brought significant environmental pressure, making marine environmental governance a challenging task. There are differences in the level of economic development among different regions within Guangdong, making it challenging to coordinate development.

In conclusion, the capacity of the establishment of MEDPZ to influence different marine economic circles should vary. Therefore, This research suggests Hypothesis 2: There is heterogeneity in the effects of the establishment of MEDPZ on distinct coastal economic circles.

2.3 Theory and assumption of the impact mechanisms

The theory of innovation-driven development posits that scientific and technological advancement affects environmental governance and economic growth (Hunjra et al., 2024; Dzhunushalieva and Teuber, 2024). Firstly, technological advancements have allowed conventional marine industries, including shipbuilding and fisheries, to enhance their operations in order to increase efficiency and safety. This upgrading not only enhances the competitiveness of these industries in the global marketplace but also reduces operating costs and improves output and quality (Carrier et al., 2023; Hong et al., 2024). Secondly, the sustained investment in science and technology has resulted in the development of environmentally favorable operational technologies and processes, including those that improve energy efficiency and reduce polluting emissions (Kuehne et al., 2024). In addition to addressing the broader global demand for sustainable development, these innovations also mitigate adverse effects on the marine environment. The marine industry's social responsibility and market acceptability are thereby improved by the popularization of environmentally benign technologies, thereby fostering the sustainable and healthy development of the marine economy (Salihi et al., 2024).

One of the significant technological advancements in the pilot provinces has been the development of marine renewable energy. For example, in Shandong Province, the government has implemented policies to support the construction of offshore wind farms. These projects not only enhance the province's energy security but also reduce carbon emissions, contributing to environmental governance. The implementation of advanced wind turbine technologies and the establishment of research centers for marine energy has been crucial in this regard. In Zhejiang Province, the government has invested heavily in marine biotechnology. Specific programs include the development of new marine drugs and bio-products. The establishment of the Zhejiang Marine Biotechnology Research Institute has facilitated the commercialization of marine biotechnology, leading to the development of high-value-added products. These innovations have not only boosted the marine economy but also improved environmental governance by reducing the reliance on traditional, more polluting industries. In Liaoning Province, the focus has been on advanced shipbuilding technologies. The government has provided financial support and tax incentives for the development of high-tech shipyards. These initiatives have led to the construction of more efficient and environmentally friendly ships. The implementation of innovative manufacturing technologies in shipbuilding has significantly reduced production costs and improved product quality.

This research suggests Hypothesis 3a: The establishment of MEDPZ impacts economic growth and environmental governance by enhancing scientific and technological advancement in the pilot provinces.

The government regulation establishes a controlled and organized operational milieu by bolstering the execution of marine policies, including stringent implementation of legalized laws pertaining to the exploitation of marine resources and safeguarding the environment. This enhanced enforcement decreases the environmental and economic hazards linked to mismanagement and establishes a more stable and predictable operational structure for marine economic activity (Shih, 2024). Furthermore, The government regulation has established uniform norms and criteria for the use of marine resources. The implementation of controlled management not only guarantees the logical distribution and safeguarding of resources but also fosters the uniformity of technology and the systematic advancement of industry (Yu and Bi, 2019; Roland et al., 2022). Consequently, this aids in sustaining the marine environment and facilitating long-term economic progress.

The establishment of MEDPZ has led to the implementation of stricter environmental protection laws and regulations (Wang et al., 2024). For example, in Guangdong Province, the government has enacted policies to control marine pollution from industrial sources. Specific regulations include stricter emission standards for factories located near the coast and the implementation of pollution control technologies. These measures have significantly improved the marine environment. In Hainan Province, the government has implemented comprehensive marine spatial planning. This includes the designation of marine protected areas and the establishment of ecological corridors. These planning initiatives have helped in the sustainable use of marine resources and the protection of marine biodiversity. The implementation of these plans has been supported by advanced monitoring technologies to ensure compliance. In Fujian Province, the government has introduced eco-compensation mechanisms to promote sustainable development. Specific programs include financial incentives for enterprises that adopt environmentally friendly practices. The establishment of these mechanisms has encouraged companies to invest in green technologies, thereby reducing their environmental footprint.

This research suggests Hypothesis 3b: The establishment of MEDPZ impacts economic growth and environmental governance by enhancing government regulation in the pilot provinces.

3 Data and variables

3.1 Study area and data sources

The coastal provinces examined in this research are distributed within China's three primary marine economic spheres: North,

East, and South. The northern marine economic circle covers the economic region constituted by the coastal areas of the Liaodong Peninsula, Bohai Bay, and Shandong Peninsula, primarily encompassing the sea and land regions of Liaoning Province, Hebei Province, Tianjin Municipality, and Shandong Province. The eastern marine economic circle comprises the economic region along the Yangtze River Delta, mainly including the sea and land areas of Jiangsu Province, Shanghai Municipality, and Zhejiang Province. The southern marine economic circle includes the coastal areas of Fujian, the Pearl River Delta and its flanks, the Beibu Gulf, and Hainan Island. It primarily encompasses the sea and land areas of Fujian Province, Guangdong, Guangxi Zhuang Autonomous Region, and Hainan Province. The data in this research are primarily from the China Marine Statistical Yearbook, China Environmental Statistical Yearbook, China Regional Economic Statistical Yearbook, China Urban Statistical Yearbook, the WIND database, and the Bulletin on the Ecological and Environmental Status of China's Marine Areas.

3.2 Variables

3.2.1 Dependent variables

Economic growth is measured by the proportion of gross marine regional product (GMRP) within the gross regional product (GRP), which reflects the comparative significance of the marine sector within the overall regional economy. Recent studies support this measure. For example, Wang et al. argue that the GMRP-to-GRP ratio effectively captures the economic contribution of the marine sector and provides a clear benchmark for assessing the impact of policies aimed at enhancing marine economic development (Wang H. et al., 2024). Additionally, Ji et al. have shown that the marine economy's contribution to regional GDP is a critical factor in evaluating the effectiveness of economic policies in coastal regions. These findings further validate the use of GMRP/GRP as a robust measure of economic growth in the context of marine economic development (Ji et al., 2024).

The choice of emissions intensity as a measure of environmental governance is also well-founded in recent research. Liu and Li highlight that emissions intensity, defined as the total quantity of emissions per unit of polluting source, is a key indicator of a region's commitment to environmental governance. This metric effectively captures the relationship between economic activity and environmental impact, making it a suitable proxy for assessing the effectiveness of environmental policies (Liu et al., 2022). Moreover, Dong et al. have demonstrated that emissions intensity is critical in understanding the interactions between economic growth and environmental sustainability (Luo et al., 2020). By using emissions intensity, this study aligns with the broader academic consensus on the importance of this variable in evaluating environmental governance outcomes.

3.2.2 Independent variables

The independent variable in the research is the establishment of MEDPZ, which is measured by creating a dummy variable (DID). This variable is represented as an interaction term between time and province in the pilot region. Equation 1 displays the variables and framework of the model. The variable "year" represents the time of the pilot. It is given a value of 1 if it is in the pilot period or the subsequent years and a value of 0 if it is in the non-pilot era. The variable "province" represents the pilot province and is given a value of 1 if it is a pilot province and 0 if it is not.

TABLE 1 Variables and measurement formulas.

Variables	Indicators	Measurement Formulas
Dependent Variables	Economic Growth	Gross marine product/Gross regional product
	Environmental Governance	Total quantity of emissions per unit of polluting source
Independent Variable	DID	Policy dummy variable
Control Variables	Percentage of added value of major marine industries	Added value of major marine industries/Overall added value
	Percentage of added value of marine-related industries	Added value of marine-related industries/Overall added value
	Total amount of seawater products	Sum of total marine fishing and total mariculture
	Productivity of marine industries	Gross marine product/Number of persons employed in marine-related employment
	Degree of trade openness	(Total import and export value of goods (in dollars) * Dollar exchange rate)/Gross regional product
	Percentage of marine secondary industry	Gross product of the marine secondary sector/Gross marine product
	Percentage of marine tertiary industry	Gross product of the marine tertiary sector/Gross marine product
Mechanism Variables	Scientific and technological advancement	Marine R&D expenditures/Total regional R&D expenditures
	Government regulation	Marine management services expenditures/Regional general budget expenditures

3.2.3 Control variables

In this research, seven factors that have the potential to influence regional marine economic growth and environmental governance are chosen as control variables. The metrics include the percentage of added value of major marine industries (Yin et al., 2022), the percentage of added value of marine-related industries (Yin et al., 2022), total amount of seawater products (Liu et al., 2022), the productivity of marine industries (Fang et al., 2024), the degree of trade openness (Li et al., 2023), the percentage of marine secondary industry (Ma et al., 2019), and the percentage of marine tertiary industry (Winther et al., 2020). The corresponding variables and definitions are shown in Table 1.

3.2.4 Mechanism variables

Scientific and technological advancement is measured by the percentage of marine R&D expenditures to total regional R&D expenditures. The Global Innovation Index 2024 report highlights that R&D expenditures as a percentage of GDP are a critical indicator of a region's commitment to scientific and technological advancement. This metric effectively captures the resources allocated to research and development activities, essential for driving innovation and technological progress. Additionally, the report indicates that R&D expenditure is a key driver of innovation and economic growth, particularly in the marine science and technology sectors. By using the percentage of marine R&D expenditures to total regional R&D expenditures, this study aligns with the broader academic consensus on the importance of this variable in evaluating scientific and technological advancement (World Intellectual Property Organization, 2024).

The percentage of marine management measures government regulation services expenditures to regional general budget expenditures. This measure is supported by recent research on the impact of government spending on environmental governance and marine economic development. For example, Hong and Guan emphasize that government regulation and investment in marine management services are crucial for improving environmental performance and supporting sustainable economic development within the marine sector. The study highlights that increased expenditures on marine management services can lead to better governance outcomes, including enhanced protection of marine ecosystems and more efficient use of marine resources (Hong and Guan, 2024). Furthermore, Li et al. include environmental governance investment intensity as a key indicator of sustainable development, reinforcing the importance of government regulation in marine economic development. Using the percentage of marine management services expenditures to regional general budget expenditures. This study provides a robust measure of government regulation's impact on marine economic development and environmental governance (Li et al., 2021). Figure 1 shows the variables and the path of influence in detail.

3.3 Model

3.3.1 Benchmark model

This research created a Time-varying DID model. Hypothesis 1 may be confirmed by examining the disparities in economic growth and environmental governance between the experimental and control groups before and after the establishment of MEDPZ. The modeling in question is outlined as follows:

$$EG_{1it}/EG_2it = \alpha_0 + \alpha_1 DID_{it} + \alpha_2 Z_{it} + \nu_i + \mu_t + \varepsilon_{it} \quad (1)$$

In Equation 1, EG_{1it} represents economic growth, and EG_{2it} represents environmental governance. The variables i and t represent pilot provinces and years, respectively. DID_{it} represents the interaction term between the pilot province and the year. α_1 is the coefficient of DID_{it}, which is the most important coefficient in the benchmark model. If the coefficient α_1 is both statistically significant and positive, it demonstrates that the establishment of MEDPZ promoted EG_{1it} or EG_{2it} in the pilot

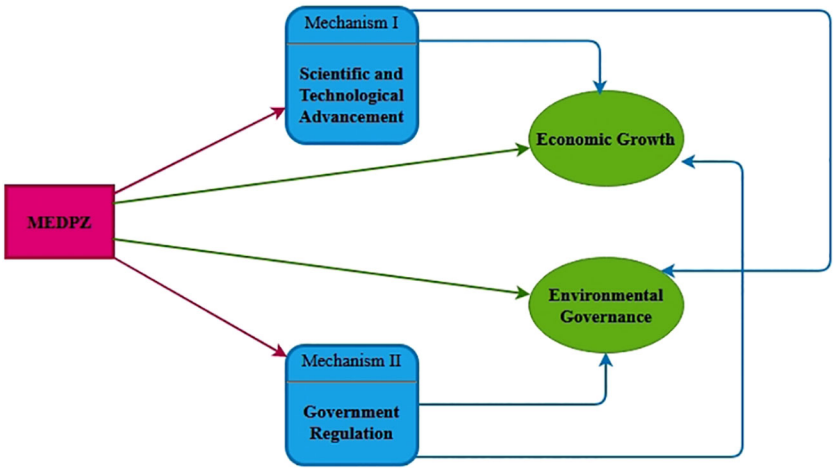

FIGURE 1
Impact pathways for the establishment of the MEDPZ.

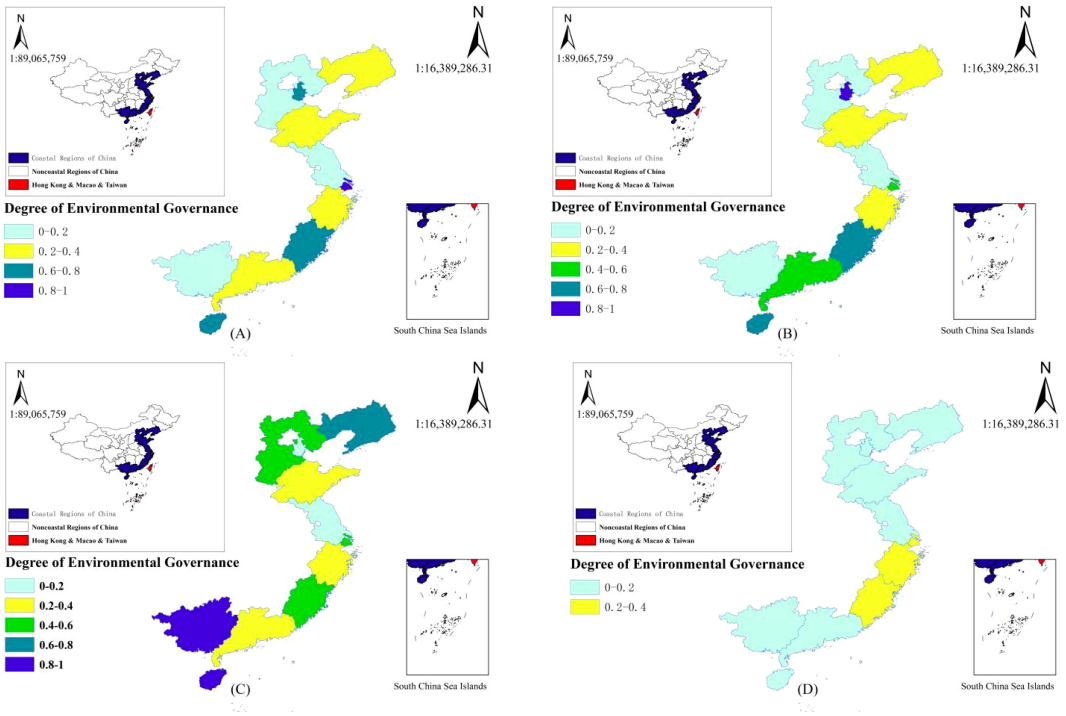

FIGURE 2
Trend in economic growth and environmental governance. **(A)** Economic Growth-2007. **(B)** Economic Growth-2021. **(C)** Environmental Governance-2007. **(D)** Environmental Governance-2021.

provinces. Therefore, Hypothesis 1 has been validated. Z_{it} is the control variable. v_i, μ_t, and ε_{it} represent the fixed effects for the province fixed effect, year fixed effect, and random perturbation term, respectively.

3.3.2 Mechanism test model

Based on Equation 1, the following model was used in this research to test the mechanism:

$$STA_{it}/GR_{it} = \beta_0 + \beta_1 DID_{it} + \beta_2 Z_{it} + v_i + \mu_t + \varepsilon_{it} \quad (2)$$

Where STA is a proxy for scientific and technological advancement, GR is a proxy for government regulation, and the remaining variables are defined in the same manner as in Equation 1. If the coefficient β_1 of the DID is both statistically significant and positive, it proves that the establishment of MEDPZ will promote the STA or GR in the pilot provinces.

4 Results

4.1 Trend in economic growth and environmental governance

In Figure 2, regarding marine economic growth, the three primary marine economic circles exhibit steady trends over the inspection period. Specifically, Hebei, Jiangsu, and Guangxi exhibit low marine economic growth. Liaoning, Shandong, and Zhejiang fall in the intermediate range. Guangdong, Shanghai, Fujian, and Hainan demonstrate a higher rate of marine economic growth, while Tianjin stands at the highest level. In terms of environmental governance, in 2007, The southern marine economic circle exhibited superior performance, followed by the north, while the eastern marine economic circle had the lowest level of environmental governance. Guangxi, Hainan, and Liaoning exhibit superior environmental governance among the provinces, with Hebei and Fujian following closely. Meanwhile, Shandong, Zhejiang, and Guangdong have relatively poor environmental governance, while Jiangsu has the

TABLE 2 Result of the benchmark model.

Variables	Economic Growth		Environmental Governance	
	(1)	(2)	(3)	(4)
DID	2.843***	1.222***	1.072*	0.748*
	(0.891)	(0.298)	(0.510)	(0.392)
Control	No	Yes	No	Yes
Province Fixed Effect	Yes	Yes	Yes	Yes
Year Fixed Effect	Yes	Yes	Yes	Yes
Constant	18.45***	-11.43*	2.362***	1.310
N	165	165	165	165
R^2	0.333	0.745	0.444	0.570

Robust standard errors for clustering at the city level are in parentheses. ***p<0.01, **p<0.05, *p<0.1.

lowest degree of environmental governance. In 2021, the overall environmental governance level of the coastal provinces has decreased, but the environmental governance performance of Fujian and Zhejiang remains exceptional.

The Environmental Kuznets Curve (EKC) theoretical assumptions (Grossman and Krueger, 1995) align with the current sustained and stable development of the marine economy and the relative deficit in environmental governance in China's coastal provinces. The theory posits that environmental quality will deteriorate during the initial phases of economic development due to economic growth. However, after reaching a certain threshold, environmental contamination will progressively decrease and subsequently improve as economic development continues. The establishment of the MEDPZ is in its infancy, and coastal provinces are generally experiencing more intense industrialization and urbanization, exacerbating the exploitation of marine resources and pollutant emissions. It is anticipated that the urgency of environmental governance will be increasingly recognized by coastal areas, resulting in a rise in their investment in environmental protection as the marine economy continues to expand. Consistent with the pattern of economic growth about enhanced environmental quality depicted in the EKC curve, this change is expected to result in a climax and subsequent decline in environmental pollution.

4.2 Result of the benchmark model

Table 2 presents the estimated outcomes of Equation 1. Model (1) and model (3) control for Province fixed effect and year fixed effect, while model (2) and model (4) incorporate all control variables. The findings from models (1) and (3) indicate that the coefficients of the variable DID are statistically significant at the 1% and 10% levels, respectively, with a positive effect. This demonstrates that the formation of the MEDPZ has greatly enhanced both economic growth and environmental governance in the pilot provinces. Based on model (2) and model (4), The establishment of the MEDPZ had a substantial positive impact on economic growth in the pilot provinces, increasing it by around 1.222 percentage points. Additionally, it led to an improvement in environmental governance by around 0.748 percentage points. As a result, Hypothesis 1 was confirmed.

The DID model reveals that the positive effects of the establishment of MEDPZ on environmental governance do not contradict the decline in the degree of environmental governance: Firstly, The establishment of MEDPZ has expedited attaining the EKC curve's inflection point in the coastal provinces, preventing further decline in environmental governance. Secondly, While the DID model includes numerous variables influencing environmental governance, variations in governance levels may be influenced by more intricate factors, including economic development, industrial composition, and public awareness regarding environmental protection. The establishment of MEDPZ, although a significant influencing element, may not be the exclusive one. Finally, The establishment of MEDPZ may demonstrate considerable regional variability in their effects, with pilot regions likely to see substantial advantages from MEDPZ policies. In contrast, others may have little or no influence. Overall averages may obscure advancements in environmental governance in specific places or timeframes. Consequently, this research will further investigate the spatial heterogeneity of the establishment of MEDPZ impacts in later sections to comprehensively comprehend their particular functions and effects across various geographies.

4.3 Robust test

4.3.1 Common trend test

Another fundamental assumption of the DID method is that there is no substantial disparity in economic growth or environmental governance between provinces that had established MEDPZ (the pilot group) and those that had not established such zones (the control group) before the policy was put into effect. In order to evaluate this situation, this research examines the parallel trend changes in the effects of the establishment of MEDPZ, utilizing the year before the pilot program was implemented as the reference period. Based on the test results presented in Figure 3, it can be observed that in the four years preceding the implementation of the policy, there is no significant difference in coefficients between the

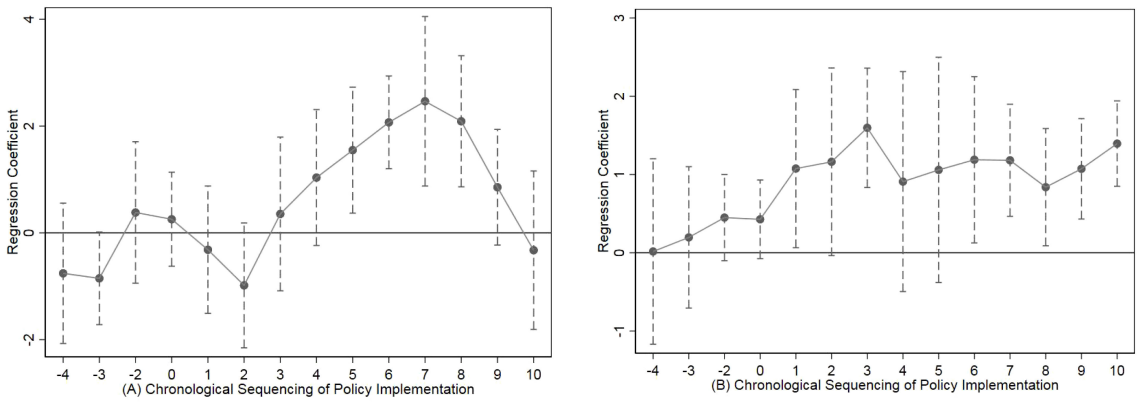

FIGURE 3
Result of the common trend test. **(A)** Economic Growth. **(B)** Environmental Governance.

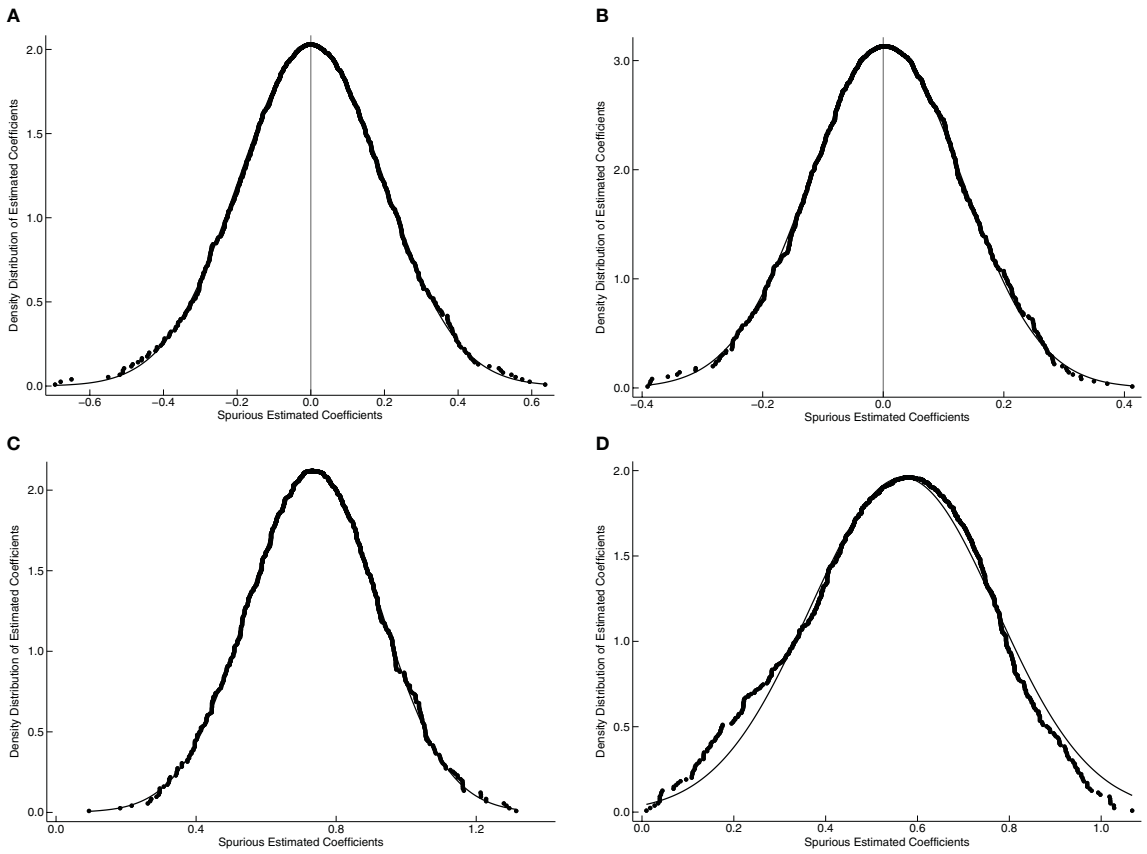

FIGURE 4
(A) Randomization of treatment and control groups - economic growth. **(B)** Randomization of Treatment and Control groups - Environmental Governance. **(C)** Randomly advance the establishment time of MEDPZ - Economic Growth. **(D)** Randomly advance the establishment time of MEDPZ - Environmental Governance.

experimental and control groups. Furthermore, the findings shown in Figure 3A indicate that the policy's effect on economic growth is substantial starting from the 5th year after its introduction but becomes insignificant from the 9th year forward. On the other hand, the outcome of Figure 3B demonstrates a continued and significant trend in the influence of policy on environmental governance, beginning from the sixth year after the policy's adoption. This demonstrates that the establishment of MEDPZ has a notable delay in its influence on the pilot zones.

TABLE 3 Result of correcting outliers.

Variables	(1)	(2)
DID	0.919**	0.648*
	(0.339)	(0.333)
Control	Yes	Yes
Province Fixed Effect	Yes	Yes
Year Fixed Effect	Yes	Yes
Constant	-10.42***	0.898
N	148	148
R^2	0.671	0.571

Robust standard errors for clustering at the city level are in parentheses. ***p<0.01, **p<0.05, *p<0.1.

4.3.2 Placebo test

This research began with a placebo test by randomizing the treatment and control groups. Specifically, The provinces in the initial treatment group are designated as the new control group, and the timeline for establishing MEDPZ remains intact. If n provinces establish MEDPZ in year t, then n provinces are randomly chosen as a new treatment group from the provinces that have not established MEDPZ in that year. The Model (2) and Model (4) in Table 2 are recalculated using a new sample, which enables the completion of 1 placebo test. Iterate the procedure above 1000 times to derive the estimated coefficients for 1000 DID variables. The estimation results depicted in Figure 4 show that the average value of the re-estimated DID coefficients is considerably smaller than estimated by model (2) and model (4). It suggests that the policy effect of MEDPZ exhibits a clear spatial bias, with the most significant impact on the economic growth and environmental governance observed in provinces that have established these zones.

In this research, the subsequent placebo test was conducted by pre-randomizing the timing of the establishment of the MEDPZ. Specifically, The assumption is that the provinces establishing

TABLE 4 Result of the spatial heterogeneity.

Variables	Economic Growth			Environmental Governance		
	Northern	Eastern	Southern	Northern	Eastern	Southern
DID	0.915*	0.919	1.842***	0.307**	0.844	0.590
	(0.366)	(0.775)	(0.519)	(0.083)	(0.452)	(0.642)
Control	Yes	Yes	Yes	Yes	Yes	Yes
Province Fixed Effect	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effect	Yes	Yes	Yes	Yes	Yes	Yes
Constant	16.9	-17.81*	50.49*	1.704	-1.48	-13.87
N	60	45	60	60	45	60
R^2	0.880	0.924	0.851	0.707	0.746	0.930

Robust standard errors for clustering at the city level are in parentheses. ***p<0.01, **p<0.05, *p<0.1.

MEDPZ remain unchanged. If province i is the pilot province for MEDPZ, then choose a random of the three years before the establishment of the pilot policy as the province's establishment date. Accordingly, the estimated coefficients of the variable can be obtained by re-estimating the model (2) and model (4) using the new sample. The above process was repeated 1000 times to obtain the corresponding estimates. As shown in Figure 4, the means of the coefficients of the variables are significantly lower than the estimates of model (2) and model (4). Consequently, randomly advancing the establishment of MEDPZ leads to a significant decrease in the economic growth and environmental governance of the pilot provinces, which also proves that the establishment of MEDPZ does improve the economic growth and environmental governance of the provinces from a counterfactual perspective.

4.3.3 Correcting outliers

This section applies outlier correction methods to models (2) and (4) of the benchmark model. Specifically, the top and bottom 5% of the samples in the model are excluded. Table 3 displays the results. The results from model (1) and model (2) demonstrate the influence of the establishment of MEDPZ on economic growth and environmental governance, respectively. There is little disparity between the altered model and the benchmark model. This further confirms the reliability of the findings from this research.

TABLE 5 Result of the impact mechanism model.

Variables	Scientific and Technological Advancement (STA)	Government Regulation(GR)
DID	0.0072**	0.0011***
	(0.0017)	(0.0002)
Province Fixed Effect	Yes	Yes
Year Fixed Effect	Yes	Yes
Constant	0.0147***	0.0018***
N	165	165
R^2	0.218	0.376

Robust standard errors for clustering at the city level are in parentheses. ***p<0.01, **p<0.05, *p<0.1.

4.4 Result of the heterogeneity model

This research conducts further tests on the spatial heterogeneity of MEDPZ, using Equation 1 as a basis. The results shown in Table 4 confirm that the establishment of the MEDPZ has a beneficial effect on all marine economic circles. Specifically, the coefficients of the DID indicate a significant increase in economic growth and environmental governance in the northern marine economic circle, with a statistical significance threshold of 10% and 5%, respectively. Within the eastern marine economic circle, the establishment of the MEDPZ had a notable impact on the economic growth and environmental governance of the pilot provinces. However, the statistical findings did not demonstrate a substantial degree of relevance. Within the southern marine economic circle, the establishment of MEDPZ has a considerable impact on economic growth, with a measured increase of 1.842, which is statistically significant at the 5% level of significance. However, the effect on environmental governance is comparatively smaller, with only a 0.590 increase. These findings indicate that the establishment of MEDPZ has varying impacts on distinct marine economic sectors. Consequently, Hypothesis 2 is confirmed.

4.5 Result of the impact mechanism model

Previous analyses have verified the substantial positive effects of MEDPZ establishment on the pilot provinces in terms of environmental governance and economic growth. This research further investigates the effect of potential mechanisms of scientific and technological advancement and government regulation in accordance with Equation 2.

The results of the regression analysis in Table 5 show that the coefficients of scientific and technical advancement and government regulation in Equation 2 are statistically significant at the 5% and

10% levels, respectively. Specifically, the establishment of the MEDPZ enhances the degree of scientific and technical advancement in the pilot zones by about 0.0072 and the degree of governmental regulation by around 0.0011. Furthermore, previous studies have shown that science and technology advancement (Lombard et al., 2023; Song et al., 2021) and government regulation (Ye et al., 2021; Ge et al., 2022) have had a positive effect on economic growth and environmental governance. In conclusion, The establishment of the MEDPZ has enhanced economic growth and environmental governance in the pilot provinces via the promotion of scientific and technological advancement and government regulation. As a result, Hypothesis 3 of the research has been confirmed.

5 Conclusions and recommendations

5.1 Conclusions

This study employs a Time-varying Difference-in-Differences (DID) model to assess the impact of Marine Economic Development Pilot Zones (MEDPZ) on marine economic growth and environmental governance in China's coastal provinces. The establishment of MEDPZ significantly enhances marine economic growth and environmental governance, with increases of 1.222 percentage points and 0.748 percentage points, respectively. The effects vary spatially, with the northern marine economic circle benefiting the most, the southern circle experiencing substantial economic growth but less environmental improvement, and the eastern circle showing minimal impact.

This study employs empirical analysis to examine the dual impact of the MEDPZ policy in China on economic growth and environmental governance. The findings indicate that the establishment of MEDPZ has significantly propelled marine economic growth in the pilot provinces and enhanced environmental governance, thereby fostering sustainable economic development. This conclusion is consistent with existing research, such as the study by Hong and Guan, which posits that effective marine governance can significantly bolster the sustainable development capacity of the marine economy (Hong and Guan, 2024). Additionally, this study identifies that advancements in science and technology and the strengthening of government regulation are crucial mechanisms underlying the success of the MEDPZ policy, echoing the findings of Ge et al. (2022).

Further analysis reveals regional heterogeneity in the impact of MEDPZ policies on marine economic growth. The northern marine economic circle has benefited the most in economic growth and environmental governance. In contrast, while the southern marine economic circle has experienced substantial economic growth, the improvement in environmental governance has been relatively modest. This regional disparity aligns with the research by Johnson et al., who argue that the impact of marine economic development on environmental governance varies across regions and calls for tailored policy measures (Johnson et al., 2022). Moreover, Carrier et al. have demonstrated that the development of the marine economy exhibits a "Matthew effect," where regions with stronger economic foundations tend to perform better in marine governance, further driving economic prosperity (Carrier et al., 2023).

5.2 Recommendations

1. Considering the diverse effects of the northern, eastern, and southern marine economic circles on economic growth and environmental governance, policymakers should create and execute marine economic development plans that are specifically designed to accommodate the unique characteristics of each region. In order to foster technological innovation and industrial upgrading in the offshore engineering equipment and shipbuilding industries, as well as to enhance the environmental governance and port logistics of heavy industries, the northern marine economic circle should prioritize policies that capitalize on its marine resources and heavy industrial base. In the eastern marine economic circle, policies should be implemented to promote the green transformation of the marine economy by upgrading environmental standards and technological innovation while also fostering the development of marine financial services and marine biotechnology, given the region's well-developed financial services and high-tech industries. The southern marine economic circle should leverage its extensive marine biodiversity and tourism resources to foster the development of marine biotechnology and marine tourism industries while simultaneously bolstering its efforts to address coastal erosion, marine pollution, and exploitation.

2. Considering the crucial significance of scientific and technological advancement in fostering economic growth and environmental governance in the marine sector, the government must enhance its financial backing for research and development in marine science and technology. This support should be specifically directed towards marine biotechnology, marine energy, and environmental protection technology. The objective is to build and enhance a system for cultivating expertise in marine science and technology while also providing training for professionals in marine economics and environmental governance. This will be achieved via collaboration with higher education institutions and research organizations. Promote collaboration among firms, research institutes, and universities to facilitate the conversion of scientific and technical advancement and enhance the overall technological prowess and competitiveness of the marine sector.

3. Enact and enforce more stringent regulations regarding the protection of the marine environment, which should include guidelines for the release of pollutants, rules for the exploitation and utilization of marine resources, and systems for compensating for ecological damage. These measures aim to minimize the adverse effects of industrial activities on the marine environment. Enhance the establishment of a monitoring and evaluation system for the marine environment and use advanced information technology, such as remote sensing monitoring and big data analysis, to enhance the ability to monitor the status of the marine environment in real-time and provide early warnings. Facilitate the engagement of the general public in safeguarding the marine environment, enhance public consciousness regarding marine environmental preservation through educational initiatives and promotional campaigns, and foster the involvement of

local communities and non-governmental organizations in projects aimed at marine environmental governance and ecological conservation.

6 Limitations and future research directions

6.1 Limitations

While this research provides valuable insights into the dual advancement of marine economic growth and environmental governance through the establishment of Marine Economic Development Pilot Zones (MEDPZ), several limitations should be acknowledged:

Policy Implementation Variability: The effectiveness of MEDPZ policies may vary due to differences in local implementation and enforcement. This study assumes a uniform impact of the policy across pilot provinces, which may not reflect the actual variations in policy execution.

External Factors: The study focuses on the impact of MEDPZ policies, but other external factors, such as global economic trends, technological advancements, and policy changes at the national or international level, may also influence marine economic growth and environmental governance. The current analysis does not fully account for these factors.

Mechanism Analysis: The mechanism analysis suggests that scientific and technological advancement and government regulation are key drivers of the observed impacts. However, the study does not adequately examine the specific policies or programs that contribute to these mechanisms. Future research could delve deeper into the policy instruments and their effectiveness.

6.2 Future research directions

6.2.1 Policy implementation variability

In-depth Case Studies: Conduct detailed case studies of individual pilot provinces to understand policy implementation challenges and successes. This can help identify the factors that contribute to variations in policy effectiveness.

Comparative Analysis: Compare the implementation of MEDPZ policies across different provinces to identify best practices and areas for improvement. This can provide insights into how to enhance policy execution and enforcement.

Stakeholder Interviews: Engage in stakeholder interviews with local government officials, businesses, and community members to gather qualitative data on the implementation process and its impact on the ground.

6.2.2 External factors

Global Economic Trends: Incorporate global economic data and indicators to assess how external economic conditions affect the performance of MEDPZ. This can include trade policies, global market demand, and economic recessions.

Technological Advancements: Track and analyze the impact of emerging technologies on marine economic growth and environmental governance. This can involve studying the adoption of new technologies in the pilot provinces and their contribution to economic and environmental outcomes.

Policy Changes: Monitor and evaluate the impact of national and international policy changes on the effectiveness of MEDPZ policies. This can include changes in environmental regulations, trade agreements, and marine conservation policies.

6.2.3 Mechanism analysis

Policy Instrument Analysis: Conduct a detailed analysis of the specific policies and programs implemented under the MEDPZ initiative. This can help identify which policy instruments are most effective in promoting scientific and technological advancement and government regulation.

Program Evaluation: Evaluate the effectiveness of specific programs and projects funded by the MEDPZ policies. This can include cost-benefit analyses and impact assessments to determine the return on investment for these programs.

Cross-sectoral Collaboration: Study the role of cross-sectoral collaboration in implementing MEDPZ policies. This can involve examining how different sectors (e.g., government, academia, industry) work together to achieve the goals of the MEDPZ initiative.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found in the article/supplementary material.

Author contributions

ZL: Data curation, Resources, Validation, Software, Writing – original draft. ZS: Data curation, Funding acquisition, Methodology, Visualization, Writing – review & editing. YZ: Formal analysis, Project administration, Supervision, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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