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Special Issue Reprint

Marine Economic Development and Conservation

Edited by
Shuhong Wang and Sheng Xu

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Contents

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Editorial

Marine Economic Development and Conservation

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The ocean is an important component of modern economic development and social activities, and acts as a natural source for ecologically sound and sustainable development. The ocean also offers opportunities for new growth in terms of economic breakthroughs and innovations, acting as a key part of the overall composition of social development; however, in contrast, it can also become a bottleneck and restrict socioeconomic development. As the strategic position of the ocean continues to be highlighted, issues such as the high-quality development of the marine economy, resource accounting and management, efficiency, ecological compensation and security, marine bearing capacity measurement, and the construction of monitoring, early warning, and management systems have become increasingly important.

An increasing amount of research is indicating that the quality of marine resources and the environment is related to the level of human economic development and society's environmental policy response. Although the utilization of marine resources is the only way to achieve a "strong ocean state", if the rapid growth of regional marine economies occurs at the cost of the rapid consumption of marine resources and the environment then the marine economic model will eventually lead to the depletion of marine resources and the exposure of environmental problems. The applications of the digital economy, artificial intelligence, big data, and cloud computing technologies have recently provided new opportunities for the conservation and protection of the marine economy. Appropriate methods have been selected to explore the marine economy and meet the needs of the goals of sustainable development and the protection of the marine economy.

Twelve articles are published in this Special Issue, eleven research articles and one review, covering a wide range of marine resources, industrial structures, technologies, and ecological economics. In addition, this Special Issue also examines compounds that are not commonly monitored but have the potential to enter the environment and cause known or suspected adverse effects on the economy and resources.

Among these research articles, the paper by Shuhong Wang et al. [1] describes the four frontiers of marine economics and management that result in marine development: marine economy, marine resources, marine ecology, and marine accounting. To use different types of marine resources more efficiently, it is necessary to apply a property rights system of natural resources to marine fields. The good quality of the marine economy is guaranteed by marine ecology. The growth of the marine economy is based on successful marine accounting with the goal of identifying a breakthrough for transforming and upgrading marine industry structures, improving the marine economic governance system, and strengthening the modernization of marine governance capacity in order to better develop and utilize the ocean.

Therefore, the main goal of this Special Issue was to collate studies investigating the following: (1) high-quality development and pollution, as in the paper by Jianyue Ji et al. [2,3]; (2) marine industrial structures and technology, as discussed by Xue Jin et al. [4], Yingying Liang et al. [5], Xin Shan and Yun Cao [6], and Yanfang Sun et al. [7]; and (3) marine

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resource constraints and management, highlighted in studies by Hongjun Guan et al. [8], Chun-Yu Lin et al. [9], Shuhong Wang et al. [10], and Zhe Yu et al. [11].

The papers collected in the Special Issue focus almost entirely on analyses of China's situation, which is of course important but presumably not the only one to be considered in dealing with the issue of "Marine Economic Development and Conservation". As of now, China is more focused on the immense potential of blue granaries, blue medicine warehouses, and ocean ranches, which could improve the quality of human life. Blue carbon sinks can help reduce the effects of global carbon emissions. The ocean is a treasure. How to develop ocean-related human activities within the carrying capacity of marine ecosystems is our future research field.

We trust that the collation of these papers contributes to further interest in the marine economy and management field.

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Review

A Review on Marine Economics and Management: How to Exploit the Ocean Well

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Abstract: With the objective of establishing methods for high-quality marine development and effective marine management, this review focuses on four dimensions of marine development: marine economy, marine resources, marine ecology, and marine accounting. The focus of marine economy research is the marine industry, with the marine circular economy being the latest research frontier. Marine resources are the foundation of the marine economy. To use different types of marine resources more efficiently, it is necessary to apply the property right system of natural resources to marine fields. The healthy development of the marine economy is guaranteed by marine ecology. How to scientifically measure marine ecological loss and evaluate the marine ecological environment carrying capacity and marine ecological security is key to the sustainable development of the marine economy. The development of the marine economy is based on successful marine accounting. The lack of marine data globally has made marine accounting controversial. The study aims to review the development history and latest research frontiers for various marine-related fields and identify existing problems in the processes of marine economic development and marine management, with a view to finding a breakthrough for transforming and upgrading marine development, improving the marine economic governance system, and strengthening the modernization of marine governance capacity, so as to better develop and utilize the oceans.

Keywords: marine economy; marine resources; marine ecology; marine statistical accounting

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1. Introduction

Along with scientific and technological developments and the increasing scope of human activities, the importance of marine resources, the marine environment, marine space, and strategies regarding marine management have been gradually realized by countries worldwide. Due to their ecological and economic value, marine resources have always been, and remain, a dynamic force for human survival and development, and the value the ocean generates continues to increase [1]. Marine research includes a combination of economic, social, and ecological elements. When exploiting and utilizing marine resources, people must not only consider economic objectives but also evaluate how that exploitation and utilization influences the local natural environment. Moreover, influences on society, the economy, and the environment after resource exploitation should also be preliminarily evaluated. The dynamic nature of marine exploitation has allowed previously unusable marine materials or marine environmental factors to become utilizable. However, although ocean development has continuously increased in breadth and depth, it still faces many problems. Inefficient marine development models, unreasonable marine resource-management systems, the threatened security of marine ecology, and insufficiently comprehensive ocean statistics all have a negative effect on high-quality marine development.

The ocean is the cradle of human life and provides abundant material resources for human beings. As an important source of modern economic commodities and social activities, it is not only the focus of sustainable ecological development but also of economic and societal development. If the study of the ocean is not improved upon with better statistics, models, systems, and security measures, societal and economic development of the ocean will face further problems [2]. Therefore, the best way to utilize the ocean has become a key issue in current research. This study will review the literature related to the ocean and carry out a systematic review and summary of the economy, resources, ecology, and statistical accounting of marine resources. Based on the latest research frontiers for various marine-related fields, we may find appropriate methods and ideas to solve the problems facing marine economic development and marine management from different perspectives, and thus provide a direction for future sustainable development and effective management of the ocean.

2. Marine Economy

Recently, China has paid increasing attention to green and sustainable development of the marine economy. As an important extension of land economy, the marine economy has become another growth point for China's new era of economic development.

Each sector of the marine industry can serve as an important impetus to drive the marine economy [3], including marine tourism [4]. The marine renewable energy industry [5] is conducive to optimizing the developmental structure and improving the developmental level of the marine economy. Efficiency in the marine industry is crucial for improving the marine economy. Many scholars have found that factors affecting efficiency in the marine industry include industrial agglomeration and environmental regulation, and they have advocated for strengthening interregional cooperation in coastal areas to promote marine industry agglomeration, alleviate environmental regulation constraints, promote environmental protection and marine industry efficiency, and develop the marine economy. However, Wang et al. [6] believe that productivity can be improved in the marine industry by strengthening financial support, which will enhance the efficiency of the marine industry, thereby also improving the marine economy.

Furthermore, a reasonable marine industrial infrastructure is also crucial to the development of the marine economy. Zhu et al. [7] proposed building a diversified industrial system to enhance economic risk resistance and promote marine economic development. Zhang et al. [8] also noted that optimization of the marine industrial infrastructure is a favorable foundation for the coordinated, stable, and rapid development of the marine economy. Wang and Wang [9] evaluated the contribution of China's marine industry through input–output analysis to determine the inter-industry correlation, production induction, sector supply shortage, and employment induction effects, and explored the evolution of the marine industry infrastructure and improvement of the marine economy.

The development of the marine circular economy is very important for the marine economy overall, as this development is the only way to ensure the transformation of the marine economy development model. The development of the marine circular economy has multiple perspectives. From the development model perspective, Pardilhó et al. [10] used the extraction and utilization of marine macroalgae waste as an important model for the development of the marine circular economy. Zapelloni et al. [11] analyzed the marine equipment manufacturing sector by using fiber-reinforced polymers from a circular economy perspective to identify sustainable solutions at the manufacturing process stage. Lehmusto and Santasalo–Aarnio [12] have discussed energy utilization in the marine circular economy, analyzed the cost of lithium battery transformation through mathematical model development, and considered its feasibility as a key point of marine industry circular economy development. Fadeeva and Berkel [13] posit that a custom marine plastic-pollution policy that integrates the circular economy and life cycle perspectives is crucial for the recovery of fishery productivity and the development of the marine circular economy.

From the development measurement perspective, Ding et al. [14] have considered the two-way connection between economic production and environmental treatment subsystems in the marine circular economy system, which can be used to evaluate marine circular economic performance. Guo and Li [15] previously discussed marine circular economy theory, defects in China's current marine circular economic fiscal and tax policies, how to promote marine circular economic development, and the feasibility of fiscal policy construction. Zapelloni et al. [11] examined sustainable production solutions for marine equipment and stressed the importance of a circular economy.

3. Innovation in Marine Science and Technology and Marine Economy

Many scholars have studied marine scientific and technological innovation at the regional and industrial levels [16,17]. For example, at the regional level, Zhong et al. [18] found significant differences in marine scientific and technological innovation in China's coastal areas from 2006 to 2016. Chavez Estrada et al. [19] and Alvarez et al. [20], respectively, studied the scientific and technological innovation of fishing boats in Chile and Spain, and further explored the rapid development of marine scientific and technological innovation caused by collective rights management and specialization. Xu et al. [21] examined the effect of science and technology finance on the scientific and technological innovation of the marine industry from the industry perspective, combining the development of and financing for scientific and technological development in the marine industry. Zhang and Wang [22] analyzed overall and partial marine scientific and technological innovation in China's coastal areas from 2006 to 2016 and found that marine industrial agglomeration and environmental regulation play a positive role in the development of marine scientific and technological innovation.

As an important driving force of the sustainable development of the marine economy, research related to marine innovation has focused on the relationship between technological innovation and the marine economy. Lawrence [23] noted that scientific and technological progress must be used to promote solutions to energy problems and explained the dialectical unity between the sustainable development of the marine economy and scientific and technological progress. Shao et al. [24] examined the short- and long-term relationship between marine economic growth technological innovation in China from 2006 to 2016 and found that they promote each other in the long term. Ren and Ji [25] studied the influence of scientific and technological innovation on the marine economy global trade finance program (GTFP) under environmental regulations in order to provide a theoretical basis for transforming and upgrading the marine economy under environmental regulations. Wang et al. [26] analyzed the interactive relationships between marine scientific and technological innovations, marine finance, and marine higher education. Wang and colleagues did this from a system-coupling perspective, and they constructed a composite system involving innovation, finance and higher education. Their system provides a decision-making reference for sustainable marine economic development. Liu et al. [27] measured scientific and technological innovation in China's coastal areas from 2006 to 2016 and found a non-linear relationship between scientific and technological innovation and high-quality marine economic development.

4. Marine Resources

4.1. Marine Resource Utilization

Marine resource development can effectively guarantee the survival and sustainable development of human society in the 21st century. The United States was among the first countries to realize the importance of marine resources and change its position regarding the ocean. The 21st Century Ocean Blueprint published in 2004 proposed, for the first time, the principle of the sustainable utilization of marine resources at the national strategic level, and established the policy goal of preserving the marine environment and protecting the integrity of the coastal environment. The National Policy for the Stewardship of the Ocean, Our Coasts, and the Great Lakes, issued in 2010, was the third national ocean policy in the United States and concerns ecosystem-based management as the basic principle of marine ecological environment conservation and the sustainable use of marine resources. In terms of marine ecological environment conservation, it puts forward requirements for protecting, maintaining, and restoring the ecological health and biodiversity of the ocean, coastal areas, and the Great Lakes region. Meanwhile, Australia also attaches great importance to the use and protection of marine resources. the Australian coast and its offshore waters can be roughly divided into four types of functional areas: ports, marine tourist areas, sea area wildlife refuges, and marine nature reserves. In these areas, artificial reclamation, reclamation, pollution, and abuse are forbidden in order to protect the marine-specific natural environment, biological resources, and biodiversity for the use of marine resources in marine fishery resource exploitation and the use of marine space resources, ocean energy resources, etc.

4.1.1. Marine Fishery Resource Utilization

Australia has established a full quota-management system for its fishing industry and legislated the electronic monitoring of fishing at sea. In examining the history of commercial fishing in southeast Australia, Santos et al. [28] noted that with technological progress and the emergence of new resources, fishing activities have moved offshore and into deeper waters. That previous study found that in southeast Australia, the relatively short history of fishing and the small size of the fishing industry played important roles in limiting the extent to which fishing affected local populations and helped the local environment to recover when fishing restrictions were put in place. The authors presented the management history of complex multi-species trawling fisheries in southeast Australia over the past three decades. They illustrated the hazards of overfishing and noted that fisheries in southeast Australia have returned to positive profitability and made broad improvements in environmental performance, particularly in managing the effects of fishing on protected species and benthic habitats.

4.1.2. Marine Space Resource Utilization

Unlike in Australia, the efficient use of marine resources in other developed countries includes the use of not only marine species, fisheries, and seawater but also marine resources in architectural spaces. Some scholars used buildings in the shallow sea area of Kyushu prefecture, Japan as examples of buildings that should be investigated with regard to functionality, structure, setting, location conditions, offshore construction processes, and post-construction challenges. These scholars noted that, functionally, the structures of these buildings can make full use of regional marine resources and environments. Structurally, these buildings' architects consider the harsh environmental conditions of the coastal areas and provide architectural space at the beginning of construction. Therefore, marine architectural planning should combine use, function, and infrastructure with marine conditions. Ummerhofer et al. [29] analyzed marine resource characteristics in the Indian Ocean, which is conducive to the effective and rational exploitation and utilization of marine resources and the sustainable development of human society. As a result of social progress, the demand for the efficient use of marine space in the form of marine architecture is already high. Some scholars have noted that in Canada, due to the intensification of marine environmental activities and competition, access to marine resources and the utilization of marine space are important issues of concern in many coastal areas. From a policy perspective, such scholars have argued that the use of coastal areas should be a priority in all policy decision-making processes related to Canada's oceans and that the "access" system should be implemented to realize the effective use of marine space resources.

4.1.3. Marine Energy Resource Utilization

Marine energy generally refers to renewable natural energy contained in the ocean, mainly including tidal energy, wave energy, ocean current energy (tidal current energy), seawater temperature-difference energy, and seawater salt-difference energy. In a broader sense, marine energy also includes wind energy over the ocean, solar energy on the ocean surface, and marine biomass energy [30]. Extracting wave energy from the ocean is a promising solution for renewable energy production because of the high energy intensity of waves compared to other renewable energy sources [31]. China has rich ocean energy resources at an internationally advanced level for marine energy accumulation ability. However, the marine energy industry is still in its infancy, and China's proposed peak carbon and carbon-neutral strategy to achieve green energy and power transformation also provides a crucial opportunity for the development of marine energy resource use [32].

4.2. Natural Resource Property Rights System

As a type of natural resource, the management of marine resources is based on and referenced by the system of natural resource property rights. Natural resource property rights determine the allocation efficiency of economic resources and provide an important basic system for strengthening ecological protection and promoting the construction of ecological civilization. Consummate with the system of natural resources in the rights system is the premise of natural resources property rights system reform. Therefore, the study of specific rights within the natural property rights system results in many different viewpoints. The right to resources can be defined as a person's legal right to the rational utilization of natural resources, including natural resource rights and artificial resource rights. Reform of the paid use system of natural resources owned by society as a whole is a key part of the reform of the property rights system for natural resources. Some scholars have proposed that natural resource rents, renewable energy, and urbanization reduce ecological footprints, indicating that they have a positive contribution to environmental quality. Institutional reform will guarantee the transformation of the natural resource property rights system and will accelerate the implementation of the system accordingly.

Some studies have posited that the implementation and transformation of the natural resource property rights system needs to break through conventional administrative means, actively innovate the administrative supervision system, and overcome the "last kilometer" of transformation from institutional system construction to governance efficiency. This is particularly important. Pamela Jagger et al. [33] proposed that the reform of the natural resource property rights system must adhere to the principle that nothing prohibited by law can be done. All manner of civil subjects can equally enjoy all types of civil rights related to natural resources according to law, and these rights should be strictly protected to ensure that any infringement is remedied. Only in this way can the civil rights of natural resources, including marine resources, be added to the "protection lock" and "safety gate" of the rule of law. Studies have also emphasized that legal systems should be used to facilitate the implementation of the system of natural resource property rights; however, China has mainly adopted conventional administrative means, such as supervision, inspection, notification, and accountability. The use of environmental taxes is also an effective implementation method, and one that is likely to be applied to matters related to the marine environment, as well as to those of other areas and countries [34]. Thomas Sikor et al. [35] also proposed that the policy system of natural resource property rights must transform its objectives and legislatively confirm abstract environmental policies by virtue of the standardization and stability of laws to ensure the effective implementation of the system.

4.3. Marine Resources Management System

Regarding marine resource management systems, the United States has taken the global lead. Singleton [36] conducted research on fishery resource management in the Pacific Northwest and posited that when establishing a community-based or jointly-managed natural resource management system, the participation of national government departments could effectively improve the probability that the system will be successfully established. Although the current relationship between the state and the community is relatively tense, the natural resource management model is extensive. However, the establishment of a common natural resource management system should not completely overturn the existing management model and then re-establish a new model, but should gradually improve the existing model, a process in which social trust plays an important role. Borja et al. [37]

and Fulton et al. [38] have posited that the United States is a country that typically combines centralized and decentralized management systems. The administration of maritime affairs in the United States is distributed among federal agencies, whereas maritime law enforcement is centralized by one agency. In the United States, state governments are responsible for marine resources within a three-mile territorial sea offshore area, whereas the federal government is responsible for marine resources from 3–200 nautical miles offshore. Laws and programs enacted by the federal government are functionally carried out by federal executive agencies. Sutton–Grier et al. [39] studied three acts protecting coastal zones and marine habitats—the Clean Water Act, the Coastal Zone Management Act, and the Oil Pollution Act—from the perspective of coastal blue carbon resources. They found that the federal government has already integrated some ecosystem functions and services into existing resource regulation and pollution reduction practices. If carbon resource regulation is integrated into the existing regulatory system as an additional ecosystem service, no legislative obstacles exist from a legal perspective. This only depends on advanced science that can more accurately measure the movement and emission rates of blue carbon between different environments and marine habitats.

In France, the Marine Fishery and Aquaculture Management Bureau, the Marine Oil, Gas and Other Mineral Resources Management Bureau, and the Marine Renewable Energy Management Bureau are under the French Ministry of Oceans. The coastal regions, provinces, and cities have also established corresponding marine resource management agencies, thereby forming a typical centralized management system of marine resources. The United Kingdom is a country that typically implements a decentralized marine management system. The Ministry of Maritime, Air and Environmental Group is responsible for the coordination of government ministries of foreign-related maritime policy and law. The Ministry of Communications is responsible for maritime traffic safety management and marine environmental protection and survival. The Department for Environment, Food and Rural Affairs is responsible for 200 nm fishing area management and fishery resource protection. The Department of Energy is responsible for managing oil and gas resource development. The Land Commission regulates seabed and beach placer mining, and the Coal Board regulates seabed coal development, among other things.

5. Marine Ecological Environment

5.1. Marine Ecological Environment Protection

5.1.1. Marine Ecological Loss Assessment and Compensation

The scientific definition of “marine ecological damage” is the premise of damage assessment and damage relief. However, no universally recognized definition of “marine ecological damage” is available at present, although many scholars and relevant legal systems of European and North and South American countries have elaborated on the concept of “ecological damage” or “environmental damage”. For example, Lahnstein [40] posits that ecological damage refers to “physical damage to nature; that is, damage to soil, water, air, climate, landscape, animals and plants living in it and their interactions”. E. S. Scheblyakov et al. [41] has defined the concept of environmental damage as “the change, deterioration, or destruction of any part or whole of environmental resources, resulting in adverse effects on human beings and nature”. In 2000, the European Union’s White Paper on Environmental Responsibility defined environmental damage as “including damage to biodiversity and damage in the form of polluted sites”. In 2004, the EU Environmental Responsibility Directive on the Prevention and Remedy of Environmental Damage (2004/35/CE) [42] clearly included “damage of Natural Resource Service” into the scope of what is considered “damage”.

Ecological damage assessment is an entire process, from the physical condition of ecological damage to the expression of monetary value. By confirming the ecological damage caused by human activities or pollution events, economic measurements of the damage are conducted, and the ecological damage is expressed with monetary indicators. Two problems are involved in determining the physical amount of ecological damage.

The first is how to select a variable index that represents ecological damage (i.e., damage factor). The second is how to determine the amount of ecological damage. Cendrero [43] and de Mulder et al. [44] found that damage factors caused by reclamation mainly focus on fishery resources, mammals such as seals, habitat resources such as mangroves and coral reefs, wetland water quality, and coastal tourism resources such as beaches. Studies have also been conducted on marine ecological damage caused by toxic leaks and land-based pollution. For example, McConnell et al. [45] have all analyzed land-based pollution and other emergencies and evaluated the damage they cause to fisheries and beaches.

Compensation for ecological damage is based on the previous environmental utility level of individual members of the public who suffer losses, and standard compensation is the monetary amount that can ensure the integrity of environmental welfare on an individual level. Based on the above definition, several scholars have used environmental resource value assessment methods to conduct monetary assessments of resource or ecological damage in emergencies, such as oil spills and dangerous chemical leaks, and take this as the basis for measuring damages.

5.1.2. Coastal Zone Ecological Environment Management and Protection

Several scholars have studied ecological environment management modes of coastal zones. For example, Hassanali [46] proposed the use of more sustainable, fair, and feasible means to manage the current ecological environment of Trinidad and Tobago's coastal region. Yu et al. [47] analyzed the main driving factors of reclamation in the Beibu Gulf of Guangxi and interpreted these factors to facilitate decision making for ecological and environmental management in the gulf's coastal zone. Smith and Rodriguez–Labajos [48] analyzed an existing indicator system in coastal areas and compared this system with the needs of coastal stakeholders in developing countries, on the basis of which they proposed an indicator system that could be part of a systematic eco-environmental management framework for coastal zones.

Sea-level rise is also important to coastal ecological environment management. To ensure effective coastal ecological environment management, developed countries have specifically conducted monitoring studies on the impact of sea-level rise to identify changes in various natural systems, such as seawater intrusion, storm surge intensification, coastal erosion, and lowland inundation [49–54], which have, respectively, caused the expansion of seawater intrusion, inundation range, population migration, possible economic loss, and coastal wetland area loss in coastal zones, to reflect different types of impact and degrees of harm [55–59]. Although a comprehensive monitoring and management system for coastal ecological environment damage caused by sea-level rise has not yet been created, the development trend is gradually shifting toward comprehensive quantitative and fine management, with increased consideration provided to applying research results in coastal environment planning, design, and management.

5.2. Storm Surge Disaster Risk and Loss Assessment

The marine economy has increasingly become a new growth point for national economic development. In China, reliance on marine resources to achieve sustainable economic development against the current global marine background is an inevitable trend [60]. However, the role of this reliance in storm surge disasters should not be ignored when developing the marine economy. To reduce the possibility of storm surge disasters related to economic development and decrease losses from storm surge disasters, it is crucial to maintain a reasonable level of economic development. Although the current level of economic development along China's coastal area is improving, it is still at a lower stage, which is not conducive to alleviating the degree of storm surge disaster losses. This urges China to actively seek methods to guide economic development and effectively consider the economic and ecological social benefits of coastal areas.

Storm surge disaster loss assessment is a systematic project involving a very wide range of methods, in which risk assessment is an important research focus. Storm surge disaster risk-assessment methods have been widely studied in European and North and South American countries and applied when conducting empirical research in various different cities. This research provides the scientific basis for formulating reasonable disaster-prevention plans and has achieved good results. The United States was the first country worldwide to conduct a national storm surge disaster risk assessment. In the early 1990s, the National Oceanic and Atmospheric Administration, in combination with the Federal Emergency Management Agency (FEMA) and state governments nationwide, conducted storm surge disaster risk-assessment work that shifted the focus of storm surge disaster prevention and mitigation in the storm surge disaster risk assessment and regionalization, providing auxiliary decisional support for government disaster prevention and mitigation departments.

In research on models and quantitative methods of disaster loss assessment, studies from the United States started earlier and achieved more results; however, a few are specifically for storm surge disaster loss assessment. The SLOSH model was first used to estimate storm surge loss in the United States in 1992. Water depth and ground digital elevation data were input into the model through a geographic information system (GIS) to determine the storm surge disaster risk area and estimate storm surge losses. The seven-step common methodology (CM) vulnerability assessment method proposed by the International Panel on Climate Change in 1997 established an assessment index system that considered five factors: social, economic, ecosystem, cultural, and historical heritage loss. Okuyama [61] added the time series concept to the static input–output model and constructed a dynamic input–output model to evaluate indirect economic losses caused by natural disasters. FEMA and the National Academy of Building Sciences developed the multi-disaster loss assessment model HAZUS-MH in 2003, which mainly examines three disaster types: earthquakes, hurricanes, and floods. In 2003, The United Nations Economic and Social Council for Latin America and the Caribbean proposed a set of methods to assess the socioeconomic impact of natural disasters, integrating loss assessments with long-term national (regional) socioeconomic development plans.

Furthermore, Narayan [62] used a computable general equilibrium model to assess tropical cyclone disaster losses and study their impact on a short-term macroeconomy. In addition, some scholars analyzed the input–output model, computable general equilibrium model, social accounting matrix, and disaster loss evaluation models (e.g., mathematical programming), and constructed a disaster-affected computable general equilibrium model to evaluate the indirect economic losses to associated sectors and associated areas resulting from the interruption of the water system in Portland, USA, caused by an earthquake disaster like the one that happened on February 28, 2001. Hallegatte [63] proposed a modeling framework based on an input–output table to examine the consequences of natural disaster losses during the reconstruction stage. Erdik and Else [64] established a new earthquake rapid-response system function to estimate the loss time of the city after an earthquake. Finally, Hayashi [65] noted that it is impossible to quickly assess economic losses after any natural disaster without post-disaster reconstruction plans and financial budgets.

5.3. Storm Surge Disaster Monitoring and Early Warning and Emergency Management

At present, relatively mature methods, such as satellites and marine and ground observation stations, have been used worldwide, to monitor and forecast typhoon storm surge formation, movement, type, and characteristics. China, the United States, the United Kingdom, Japan, and other developed countries have established storm surge disaster-prediction systems; however, research on storm surge disaster monitoring and early warning management is relatively sparse [66,67]. Regarding emergency management of storm surge disaster losses, the initial studies mostly focused on technical aspects such as GIS software specifications, spatial data acquisition technology, disaster models and their spatial distribution, and visualization results. Since then, scholars have gradually increased their research on natural disaster early warning management [68–70], and the application of GIS technology in storm surge disaster loss emergency response management has also attracted increasing attention. The success of storm surge disaster loss emergency management is affected by many factors, with the effectiveness of emergency management institutions being key to improving storm surge disaster loss emergency management efficiency. Sufficient resources and resource integration are crucial for emergency management to successfully deal with storm surge disaster losses. Furthermore, an emergency management auxiliary decision support system is important for the emergency management of storm surge disaster losses. The emergency management system of China and developed countries such as the United States, the United Kingdom and Japan has been relatively perfected. In the United States, FEMA developed a disaster assessment and simulation software system named HazUS-MH, forming a disaster emergency management mechanism based on risk management and the five-layer emergency management organization system of "federal, state, county, city, and community". In addition, FEMA has applied GIS technology to predict the hazards of natural disasters. Furthermore, the Japanese government has also invested significant human and material resources to conduct technical research on disaster prevention and mitigation of storm surges, mainly including the country's immediate response system and disaster prevention and rescue system.

6. Marine Ecosystem

6.1. Marine Eco-Economic System

The marine eco-economic system is a complex dynamic system, which includes three subsystems: marine economy, marine ecology, and marine society. From an impact mechanism perspective, Costanza [71] has argued that human beings are blindly driven by economic interests, which has seriously damaged the ocean and led to coastal disasters that cause sizeable economic, societal, and ecological losses. He has also posited that a common vision of sustainable utilization of the ocean should be developed. Beaumont et al. [72] proposed that materials and services to improve marine biodiversity could play a fundamental role in the effective utilization of marine ecosystems. From a development measurement perspective, Bolam et al. [73] and Vassallo et al. [74] have comprehensively evaluated marine economic development from aspects of the marine environment, marine organisms, and the marine ecosystem, in combination with the concept of sustainable development, and summarized the basis and methods for marine ecological evaluation.

In addition, Martinez et al. [75] showed the necessity of vigorously promoting the assessment of the marine ecological economy to realize the most valuable sustainable development in coastal areas. Jin et al. [76] scientifically evaluated marine fishery management by using the ecological and economic integration framework. Based on the economic data of coastal cities and marine ecological data, a general equilibrium model of the marine economy and the marine food chain model were combined to construct sub-models of economic and ecological systems, respectively. Armstrong [77] constructed an eco-economic model based on protected marine areas and explained how the marine economic system affects the marine ecosystem. Pioch et al. [78] proposed criteria for ecological, social, and economic benefits when studying issues in the field of marine economy.

6.2. Evaluating the Marine Ecological Environment Carrying Capacity

According to Bishop [79], environmental carrying capacity refers to the intensity of human activities that a region can permanently sustain under the conditions of an acceptable standard of living. The author stated that environmental carrying capacity refers to the ability of the natural environment or social environment system to bear human development activities without significant environmental degradation. Most studies on ecological carrying capacity are based on population ecology. Furthermore, carrying capacity can refer to "economic carrying capacity" or "ecological carrying capacity". Ecological carrying capacity refers to the equilibrium point reached between the population and the environment in the absence of hunting and other disturbances. The absence of hunting or hunting at a normal level has little impact on the population, and ecological carrying capacity is only determined by limited habitat resources, and ecosystem carrying capacity is the maximum population that a specific ecosystem can support in a specific time.

According to the different ideas regarding how ecological carrying capacity should be measured, its evaluation methods can be divided into three categories. The first category includes comprehensive evaluation methods based on various index systems, including a comprehensive evaluation index system, an ecological footprint model, a state space method, and a supply-and-demand balance method. The second category is the product cycle comprehensive evaluation method, including the cure theory method and life cycle method. Finally, the third category comprises comprehensive evaluation methods that combine different disciplines and methods, including the natural vegetation net primary productivity evaluation method, the system dynamics method, and the "3S technology" comprehensive analysis method.

By combining the characteristics of the marine economy, scholars have inherited and innovated the methods used to evaluate ecological carrying capacity. For example, Adrianto et al. [80] used Tidung Island in Jakarta as a case study to evaluate tourism activities from the perspective of the impact on the island's socioecological system through the coupling model of social and ecological carrying capacity, and then calculated the optimal carrying capacity to provide references for marine tourism management. Sun et al. [81] proposed a marine ecological carrying capacity framework and used the AHP–entropy-based TOPSIS method to evaluate marine ecological carrying capacity in Shandong Province from multiple perspectives. Du et al. [82] combined an energy system analysis of marine ranching and the accounting rules of the energy ecological footprint model to analyze the sources of uncertainty in the evaluation of marine ranching resources and environmental carrying capacity, and, based on the Dempster–Shafer evidence theory, reduced the uncertainty of the original model by introducing expert experience and an Emergy ecological footprint approach that considers uncertainty. Tang et al. [83] proposed the concept of spatial scenarios, which are highly unified in socioeconomic attributes, land cover, ecological function, and externalities, and can replace land use/land cover in the traditional three-dimensional ecological footprint model in order to establish a new coastal ecological carrying capacity assessment framework.

6.3. Marine Ecological Security

As the ocean's strategic position becomes increasingly prominent, its ecological security also becomes increasingly important [84]. Although ecological security problems are mostly caused by humans' improper use of resources and the environment, scholars increasingly believe that marine resources and environmental quality is deeply correlated with human society's economic development level and environmental policy response [85]. Although marine resource development and utilization are necessary to realize "sea power", the rapid development of regional marine economies at the expense of marine resources and the environment of consumption, so dominated by the economic development of the marine economy development mode must eventually lead to the exposure of marine resource depletion and environmental problems.

Therefore, with the continuous development and increasing utilization of the human marine economy, the concept of ecological security has been introduced into the marine field in an increasingly wide manner [86]. Marine ecological security refers to the state of equilibrium in which the marine ecosystem can maintain its structure and function undamaged or less damaged and provide balanced and stable natural resources for the sustainable development of human ecology, economy, and society within a certain spatiotemporal range. Unlike the narrow meaning of "marine ecological health", marine ecological security incorporates more extensive content, which primarily includes three aspects: the security of the symbiotic relationship between marine ecology and the marine economy, marine ecological security, and marine economic security. All three constitute a causal order: the first is the security motivation of the latter two aspects and the second aspect provides the guaranteed security of ecological services for the third aspect.

Well-known ecologists, Ma et al. [32], first proposed their theory of a "socioeconomic–natural" composite ecosystem in 1984 [87]. This theory has provided a foundation for the development of the concept and related model of the coordinated development of the ecological economy and society. As a competitive symbiotic complex of social, economic, and ecological subsystems, the marine ecological security system not only involves unilateral ecological content but also a comprehensive ecological and economic system with complex coupling relationships [88]. However, there are still relatively few specialized works on marine ecological security, with most studies mainly exploring the concept definition, evaluation, and analysis of marine ecological security. Du and Gao [89] defined marine ecological security from the perspective of the ocean itself as the ability of the marine ecosystem to recover from a certain degree of threat and maintain a healthy state. Du and Sun [84] comprehensively considered the relationship between economic development and the ocean and posited that marine ecological security is a comprehensive balance between environmental protection, resource protection, and the sustainable development of economic activities.

The marine ecosystem is complex and dynamic but is also controllable [90]. Therefore, some scholars evaluated the current status of marine ecological security based on their own research to pave the way for further optimization. For example, Gao et al. [91] conducted a dynamic evaluation on the ecological security of Pingtan Island. Du and Gao [89] constructed an evaluation index system for the safety of marine ecological pastures and identified the best path for the ecological management of marine pastures. Meanwhile, some scholars have also made methodological and theoretical innovations. Considering the complex relationships among factors affecting marine ecological conditions, Wang [85] studied the evaluation of marine ecological security based on a neural network algorithm. Focusing on issues related to marine ecological security caused by the degradation of marine ecosystem services and functions, Huang et al. [92] constructed an evaluation index system for marine ecological services and standardized the evaluation criteria and weight determination method. Bogadóttir [93] evaluated and discussed the negative impact of economic growth on the ocean and the relationship between current ocean development strategies and long-term sustainability and human well-being.

Marine ecological security has an irreplaceable role in social, economic, and natural systems. Therefore, it is necessary to reasonably monitor and evaluate the protection effect of marine ecological security and effectively solve the contradiction between economic development and ecological protection [94]. However, although many achievements of marine ecological security assessment have developed from a simple description of concepts and definitions to a point at which an accurate quantitative assessment is performed (but most of all belong to the ecological theory of the lack of evaluation), the warning effect is small, and the existing research results cannot be directly used to solve the problems of the marine ecosystem. Therefore, it is necessary to conduct more in-depth research according to the marine ecosystem's characteristics themselves [91].

7. Marine Accounting System

7.1. Statistical Accounting System of Marine Economy in China

China's relatively complete statistical system was established in 1952 but did not include marine economic statistics at that time. In 1990, the State Oceanic Administration promulgated the National Marine Statistical Index System and Index Interpretation, which covers eight categories of marine industries, including marine transportation, coastal tourism, marine fisheries, marine minerals, marine energy, seawater utilization, the marine salt industry, and marine drugs. In 1993, the scope of the marine industry statistics in China's Marine Statistics Yearbook was adjusted again to include seven categories: marine fisheries, the marine salt industry, ports and shipping, coastal international tourism, offshore oil and gas, marine science and technology and education, and marine services. In 1994, the "marine shipbuilding" industry was further added to the "China Marine Statistics Annual Report," and "marine transportation" was replaced by "ports and marine transportation". In 1995, the "Notice on Marine Statistics in Coastal Areas" was issued, marking the official start of marine economic statistics in coastal provinces and cities. This was the first marine economic statistical accounting system formulated by the State Oceanic Administration, which established the general framework of China's marine economic accounting for the future, expanded the industrial scope of marine economic statistical accounting, and provided a foundation for the subsequent improvement of marine statistical accounting.

In 1999, to further improve the marine economic statistics and accounting system, the National Bureau of Statistics implemented the System of Comprehensive Statements of Marine Statistics, incorporating marine economic statistics and accounting into the national statistical accounting system, clearly defining coastal areas and coastal provinces (municipalities and autonomous regions), and clarifying the scope of marine economic statistics. Furthermore, according to the "Classification and Code of National Economy Industries", the "Classification and Code of Marine Economy Statistics" was issued, which adjusted the principles and methods of classification of marine economy statistics, classified the marine economy statistics plan according to the order of the first, second, and third industries, increased the marine industry to 12 categories, and expanded the scope of accounting of marine economy industries. At the same time, the marine industry has made minor adjustments. These adjustments have clarified industry classifications, adapted to the needs of marine industry development, improved various types of marine economy industries, and refined classifications under each industry. In 2006, the State Oceanic Administration released the marine industry's classification and those of related industries. Through splitting and merging, the marine economic activities are divided into three levels: large class, medium class, and small class. These classes solve the problem of statistical range overlap, expand the scope of marine economic statistics calculation, and achieve hierarchical statistical accounting for marine economic regions.

To fully reflect the overall development of the marine economy and its contribution to the national economy in the China National Economic Accounting System (2002) overall framework, basic principles and calculation methods are based on the coastal marine economic accounting systems in developed countries. In 2005, China issued the Marine Economic Accounting System Implementation Plan, which first created marine economic subject accounting and basic accounting, extended the calculation of the marine economic accounting system framework, and provided accounting content such as marine economic GDP accounting, the input and output of accounting, and fixed capital accounting, while at the same time building the ocean GDP accounting methods and models. It also called for nationwide accounting of gross marine product. In 2006, the National Bureau of Statistics approved the Gross Marine Product Accounting System, which was subsequently implemented nationwide in 2007. To adapt to economic development and changes, improve the statistical system and classification, and accurately reflect the final results of marine economic activities in a certain period, several revised versions of the Gross Marine Product Accounting System were released in 2008, 2011, 2013, 2016, and 2019. The latest revision of the Gross Marine Product Accounting System in 2019 is mainly applied to the calculation of the gross marine product and marine industrial infrastructure of coastal provinces and cities. The scope of industry calculation is determined according to the Classification of Marine and Related Industries, and the specific accounting results are published through the Statistical Bulletin of China's Marine Economy [60].

7.2. Value Accounting of Marine Resource Assets

Marine resource assets accounting includes both physical quantity and value quantity accounting, which is the premise of value quantity accounting and can systematically show the actual ownership and consumption of marine resources in China and the flow of marine resource assets during the accounting period. The ultimate goal of marine resource assets physical volume accounting is value volume accounting, which requires asset valuation and adopts different valuation methods according to various development and utilization modes and resource attributes.

The asset-based management of marine resources must comprehensively consider national management requirements and accounting technical support, clarify the status and role of marine resources in the reform of natural resources and the ecological environment management system, and technologically connect environmental economic accounting with marine economic accounting [95]. Wang et al. [95] planned and designed an accounting table of expected service flows of marine ecosystems based on SEEA experimental ecosystem accounting and discussed the pricing of marine ecosystem services and the selection of asset discount rates. They also noted the possibility of using the NPV method to calculate marine ecosystem assets and create marine ecosystem asset accounts. Wang et al. [95] analyzed marine ecosystem services and their accounting and introduced the concept of the "fourth industry" on the basis of the current marine economic accounting framework, which is conducive to a more scientific assessment of the benefits, products, and services obtained from the ocean.

Although countries have made significant progress in expanding the scope of and improving the framework for marine accounting, only a few scholars have incorporated social and cultural factors into marine statistical accounting and ocean governance [96,97]. Thus, social and cultural values have not received due attention. Marine economic management decisions are also affected by incomplete information [98,99]. In this context, Perkiss et al. [100] suggests that critical accounting be incorporated into the marine statistical accounting framework to contribute to addressing issues in the ocean governance process, such as sustainability, subsidies, and illegal fishing.

7.3. Statistical Accounting Methods for the Marine Economy

The traditional statistical accounting of the marine economy ignores the prices or costs of the marine environment, which may not provide a scientific and accurate basis for the macrocontrol of marine undertakings and the formulation of marine policies. To accurately reflect the ecological and environmental costs paid during the development of the marine economy, as well as promote high-quality marine economic development, many scholars are committed to incorporating environmental prices or costs into statistical accounting for the marine economy and discussing how to build a green marine economy accounting system.

7.3.1. Stripping Coefficient Method

The stripping coefficient method can undoubtably be applied to the calculation of the total value of the marine economy, and its scientific nature has been widely recognized internationally. The main idea of this method is to select indicators reflecting marine and related industries from national income accounts and calculate the output value of marine-related industries by using the stripping coefficient. Many countries use this method to calculate the value of their marine economy. For example, Australia has mainly used the satellite accounts of the marine industry, industrial survey method, and general equilibrium model stripping method in marine economy evaluation research. In 1998, Canada issued a report entitled the "Contribution of Canadian Marine Industry to National Economy", which proposed calculating the stripping coefficient by the proportion of stripping and calculating the total output value of the marine industry by the stripping coefficient.

In October 2002, China used the stripping coefficient for the first time to conduct marine economic statistics in a national survey of maritime employment. However, it is still a significant problem to determine the stripping coefficient of all the sea-related industries at present, and the proposed methods have their own limitations. The marine fishery service, marine oil and gas industry, marine passenger transportation, marine cargo transportation, marine technology service industry, marine fishery wholesale, and marine aquatic product retail industries are suitable for the stripping method to calculate the added value of the industry. How to construct the ocean coefficient stripping method in a manner that is suitable for different industries is a key step in marine economic statistics. Therefore, the actual situation of different marine industries should be fully considered in the process of marine industry stripping, so as to construct an accurate and effective ocean industry stripping coefficient.

7.3.2. Input–Output Table

In the early discussion on the contribution of the marine economy to GNP, the input–output table of the national economy was generally used to measure the contributions; however, no input–output table of the marine economy was compiled [101]. However, as the interrelationship between marine and coastal economies became clear, countries began to refine the marine industry sector data and improve the feasibility of compiling input–output tables of the marine economy. García-de-la-Fuente et al. [102] were the first to apply the input–output model to quantify and compare the economic contributions of marine recreational and commercial fishing to regional economies in Europe. Carvalho and Inacio de Moraes [103] quantified Brazil's coastal and marine economy in 2015 by estimating and establishing the national input–output matrix of the marine sector, which was the first time that Brazil's coastal economy and marine economy were presented using the input–output model. Suris-Regueiro et al. [104] also proposed an input–output approach to comprehensively estimate the economic impact of production in the activity sectors affected by ocean planning, including the total economic impact of direct, indirect, and induced impacts.

Although much research has been conducted on input–output theory at home and abroad, some problems remain in relation to theory and application. Due to the different national conditions of various countries, it is difficult to unify the definition and classification standards of marine economic sectors, the division scope of output and input indicators is still vague, and the statistical caliber is not uniform. However, input–output is generally calculated by value quantity, which lacks the basis of physical measurement and the standard of the value quantity calculation method. At the same time, no one has proposed and solved detailed problems such as the time delay and discontinuity when compiling the input–output table or how to compile the input–output extension table for years with unpublished data. Only by clarifying the classification system of the marine sector and specific input–output accounting methods, as well as the continuity of structure and producer prices, can specific and feasible solutions be made.

7.3.3. Marine Resources Balance Sheet

The compilation of the marine resources balance sheet plays an important role in promoting the statistical accounting of the marine economy. Although neither an authoritative theoretical framework nor a compilation method has been established at home or abroad, governments and scholars in Western countries have conducted many beneficial explorations into the accounting of natural resources and the environmental economy. Havranek et al. [105] showed that developed Western countries such as the United Kingdom and the United States have strengthened the definition and protection of marine resource property rights in the form of legislation. On this basis, marine resource asset accounting has been added to the work of natural resource asset accounting and is regarded as an important part of it. Obst et al. [106] studied the relationship between marine resource consumption and marine economic growth and further proposed that marine resources should be regarded as an important part of the national asset accounting system, positing that the changes in marine resource assets should be included in the assessment indicator system for marine ecological environment development. However, there are various types and structures for the compilation of the balance sheet of marine resources, including embedded statements, independent statements, and consolidated statements. Based on the accounting method of assets and liabilities of marine resources, the compilation of physical statement of assets and liabilities of marine resources can adopt the compiling procedure of classification before synthesis, the statistical principle of stock before flow, and the accounting method of physical assets and liabilities before value. In terms of an accounting system, the Integrated Environmental and Economic Accounting System (SEEA2012) and National Economic Accounting System (SNA2008), as the most internationally recognized natural resources accounting and national balance sheet compilation systems, have important reference significance for marine resource balance sheets. However, compared with other natural resources, the survey, monitoring and statistical accounting of marine resources are more difficult because the significant characteristics of marine resources, such as seasonality, fluidity, latent nature, complexity, and the monetary measurement conditions of natural resources and environment are not mature. Thus, the concrete implementation of the preparation of a balance sheet for marine resources is considerably difficult. It is also difficult for countries to have a unified standard in terms of the category, classification, and methods of accounting items. Therefore, disputes exist in the balance sheet compilation for marine resources in terms of the definition of property rights, technical methods, and elements of value accounting, which need to be resolved.

8. Discussion and Conclusions

8.1. Discussion

The paper contributes to the study of ocean economics and management by reviewing the development history and the latest research frontiers for various marine-related fields and pointing out problems in the process of ocean development. However, the paper also has weaknesses.

First, although the review covers four dimensions—marine economy, marine resources, marine ecology and marine accounting—the scope of the study is still not comprehensive and needs to be further expanded. Most of the ocean-related literature in this paper has studied ocean development from the perspective of economics or environmental economics. In fact, other marine fields not mentioned in the paper, such as marine engineering, marine construction, marine equipment, and marine law, are also the focus of a variety of research. They are closely related to marine economics and management and are important for the better utilization of the ocean. Therefore, interdisciplinary reviews and the integration of marine research are factors that deserve further study.

Secondly, different countries have different national conditions. The stage of marine development also differs. The overview is a discussion of the current state of marine economics and management in various countries, which tends to make the conclusions lack national applicability. It is necessary to make an appropriate distinction between studies according to countries. Only in this way can the review be of practical significance and provide directional guidance and feasible policy recommendations for the development of marine economy and effective marine management in different countries. Subsequent research should continue to advance this aspect if possible.

Finally, the paper is based on a review of the literature and is somewhat subjective. The presentation of statistical data is essential if the article is to be more convincing. This content might include the number of papers on marine resources that have been published in the last five years, the frequency of marine ecology as keywords in papers, and a comparison of the number of papers in different ocean dimensions. To better define the focus of marine economy, marine resources, marine ecology, and marine accounting, and provide a breakthrough for the transformation and upgrade of marine development, the statistical data of relevant marine literature should be further collected.

8.2. Conclusions

To improve the marine economic governance system and strengthen the modernization of marine governance capacity, this study reviews the literature related to the ocean from different perspectives and provides a systematic summary of marine economy, marine resources, marine ecology, and marine accounting to clarify the focus and shortcomings of existing research.

First, with the increasing attention of the government to the ocean, the marine economy is gradually becoming an important part of scholarly research. Marine industry is the focus of the marine economy. Most studies focus on the marine industry from the perspective of industry efficiency and industry structure. The literature related to the marine industry is relatively well developed. The marine circular economy is a research frontier that has been discussed mainly from a development model and development measurement perspective. However, until now, technology to realize the marine circular economy has been rarely mentioned and needs to be further studied. As an important driving force of the marine economy, marine innovation has been highly emphasized by the government, who have tried to clarify the relationship between marine innovation and the marine economy, with the aim of promoting the high-quality development of the marine economy.

Second, marine resources are the foundation of the marine economy. Marine resources contain resources of marine fisheries, marine spaces, and marine energy, etc. Western countries recognized the importance of marine resources earlier and this is reflected through their national policies. The enactment of national laws, the improvement in the natural resource property rights system and the establishment of marine resource management system are all successful experiences that marine countries can learn from developed countries, such as the U.S., Australia, and Canada. However, for most countries, the transformation and implementation management system of marine resource property rights is not perfect and still has a number of controversial issues.

Third, the healthy development of the marine economy is guaranteed by marine ecology. Research on marine ecology mainly focuses on two aspects. One is marine ecological loss. Concept definition, assessment methods, compensation criteria, and monitoring for marine ecological loss have all been thoroughly studied. As the main source of marine ecological loss, ocean disasters, especially storm surge disasters, are the most important research areas. Another area of importance is the marine ecosystem. Relevant studies take the marine ecological environment carrying capacity and marine ecological security as the research objects. Scholars have continuously innovated the methods used to evaluate the marine ecological environment carrying capacity. Multi-aspect evaluation, the uncertainty model, and spatial scene have been proposed as the latest research. Although great progress has been made in the study of marine ecological security, most achievements of marine ecological security assessment are realized post-evaluation, meaning that these security assessments cannot play a role in early warning efforts or effectively solve the problems of marine ecological overload and marine pollution.

Fourth, developed marine economy is based on successful marine accounting. Marine research needs accurate marine data to support it. The Chinese statistical accounting system has been gradually improved, but the accounting of marine resource assets is still in the exploratory stage, and requires in-depth research in theory, connotation definition, resource asset accounting methods, and other aspects. The environmental economic accounting system (SEEA) is the most common and basic method by which to discuss the marine economic accounting system. The scope of marine accounting is expanded and the framework for marine accounting is improved through this approach. However, there are still two problems for existing research. Intangible assets, such as society and culture, are not widely integrated into the marine accounting framework. Meanwhile, it is difficult for scholars to study the compilation of the marine resources balance sheet due to the characteristics of marine resources and disputes caused by the technical methods or elements of value accounting.

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Resource Constraints and Economic Growth: Empirical Analysis Based on Marine Field

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Abstract: To explore the contribution of marine resources to marine economic growth, this study uses panel data from 2006–2019 across 11 coastal provinces and cities in China and establishes threshold regression models using marine capital, labor, and science and technology as threshold variables affecting marine resources and economic growth. The findings reveal that the impact of marine resources on marine economic growth only demonstrates a single threshold effect under the primary industry marine resources; in general, with increased capital investment, the marine economy presents a positive development trend. The impact of primary and secondary marine resources on marine economic growth has a single threshold effect of labor input, while the impact of tertiary marine resources on marine economic growth has a double threshold effect of labor input. With investment in marine science and technology, marine resource development and utilization in the primary industries have played a consistent role in promoting marine economic growth. However, the impact of this role is gradually decreasing; marine resource development and utilization in the secondary and tertiary industries shows a development pattern wherein the driving effect of marine economic growth is first large, then small, and then large again. Based on the above analysis, China should promote the transformation of labor-intensive to capital-intensive industries by increasing investment in marine capital, training marine talent, and developing marine science and technology innovation to increase the development level of China's marine economy.

Keywords: marine economic growth; marine resource; marine production factor; panel threshold model

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1. Introduction

The ocean not only supports the development of fisheries, the chemical industry, tourism, and other industries, but also provides convenient transportation routes for expanding international trade [1]. In recent years, the development of China's economy has changed dramatically. The drawbacks brought by the traditional development approach that relies on factors and investment are becoming more and more obvious, such as low economic efficiency, serious environmental pollution, and especially the increasing scarcity of land resources. Therefore, people have started to turn their attention to the ocean [2–4]. Developing and utilizing the ocean and promoting the blue economy have become not only important vehicles for coastal countries to expand their economic and social space but also new engines of world economic growth [5,6]. As early as 2013, during his visit to Southeast Asian countries, General Secretary Xi proposed a major initiative to build the "21st Century Maritime Silk Road". Subsequently, China was explicitly requested in the report of the 19th Party Congress to "adhere to the integration of land and sea, and accelerate the construction of a strong marine state", sounding the trumpet once again for constructing the same. According to the 2021 China Marine Economy Statistical Bulletin, China's gross marine product exceeded CNY 9 trillion in 2021, accounting for 15% of coastal the country's gross domestic product. This shows that the maritime economy has become an integral part of China's economic growth. Moreover, in the post-COVID-19 era, new industries have continued to expand, and the tertiary industry of coastal tourism has experienced restorative growth. Therefore, to ensure its dynamism, we need to explore the factors that contribute to marine economy growth.

Marine resources are basic but necessary, and an important driving force of marine economic development. Marine resource development and utilization play decisive roles in the structure of marine industry, marine resource competition, and marine economic development [7–9]. In the early stage of China's marine economic growth, marine resources were abundant and easily available, and a new pattern of three industries competing for development was gradually formed, along with primary industries such as marine fisheries and secondary industries such as the marine oil and gas industry, supplemented by tertiary industries, such as the marine transportation industry [10]. As the utilization of marine resources gradually approaches the limit of marine carrying capacity, the economic output of marginal marine resources has been decreasing [11]. The economic development rate has slowed considerably, and the proportion of primary and secondary industries for resource-based development has gradually declined, while the proportion of tertiary industries has gradually increased. Thus, considering the marine resource constraints, an exploration to identify methods of promoting sustainable marine economic development is urgently needed.

Increased investment in marine capital [12], marine labor [13], and marine technology [14,15] may facilitate more effective marine resource utilization to promote marine economic growth. The marine economy comprises many industries, such as fisheries, shipping, oil industries, and marine space development, most of which are asset-heavy operations; therefore, marine economic development cannot be achieved without capital investment [12]. Labor is an endogenous driver of economic growth and important evaluation indicator of regional differences at the economic-development level, also playing an important role in marine economic development [16]. The marine economy is key to promoting the high-quality development of China's economy, and marine economic development led by science and technology innovation provides essential support in constructing a strong marine state. China's technological innovation has become a vital force in driving marine economic development at a time when it has become increasingly powerful due to scientific and technological prowess [17]. In summary, if these three elements work synergistically with marine resources, they can better promote marine economic development.

The US, an early adopter of global marine resources, has long been plagued by marine resource scarcity [18]. To rationally develop marine resources, the US has increased government support and applied high-technology solutions to marine resource cultivation, which has improved the efficiency of marine resource utilization and promoted marine economic development. The present study explores whether China can increase its investment to use ocean resources more effectively based on the US experience, and whether China can increase its investment in capital and technology, considering the low cost of labor and the high cost of capital and technology in the country. In addition, different inputs have different effects on resources for economic growth; thus, the question remains as to what should be the reasonable way to increase inputs for China. Based on the above considerations, we empirically analyzed the specific situation in China and put forward corresponding policy recommendations. In this paper, using data from the China Marine Statistical Yearbook, marine data were collected from across 11 coastal provinces and cities in China. The study period is 2006–2019 because sea-related data after 2019 are not yet available.

In this empirical study, first, we classify the environmental assets as per the SEEA central framework and marine resource characteristics, and then marine resources according to their contributions to the three major industry types. For example, marine fishing and mariculture belong to marine fishery, which is the primary industry, while the marine oil and gas and marine chemical industry mainly provide energy support as the secondary industry, and the marine transportation industry is the tertiary industry. Second, we develop a fixed-effects model to explain the growth of marine resources and the marine economy, with capital, labor, and technology inputs as control variables. On this basis, these three inputs are used as thresholds to explore the mechanism of the role of marine resources in the marine economic growth process and the characteristics of change, respectively. We identify a single threshold effect of capital investment only for the relationship between primary marine resources and economic growth; however, in general, capital investment is a constant driver of marine economic growth. A double threshold effect of labor input exists only for the relationship between tertiary marine resources and economic growth, and a single threshold utility for primary and secondary marine resources. A double threshold effect of science and technology investment is observed on the relationship between marine resources and economic growth.

Below, we identify the shortcomings of the existing literature and make improvements or extensions accordingly. First, the previous literature focuses on the interaction between marine resources and the economy [8,19] or factors affecting the marine economy [8], and does not provide a detailed classification of marine resources. We divide marine resources according to their characteristics and industrial contribution to more precisely study the relationship between marine resources and marine economic growth. Second, most studies ignore the interaction between capital, labor, and technology and resources [12–14]. In this study, we fully consider these interactions and construct a threshold effect model using capital, labor, and technology as threshold variables.

2. Literature Review

The increasing population and overexploitation of terrestrial resources in China have resulted in resource depletion and environmental damage. Therefore, to achieve sustainable development, humans are gradually turning toward the ocean [2,5,6]. Since being elevated to a national development strategy in the 1990s, the marine economy has entered a period of rapid development and become a new growth point for the national economy. In particular, the introduction of the "Eleventh to Thirteenth Five-Year Plan" for the development of China's marine economy has played a substantial role in promoting the development of China's marine economy, which accounts for over 9% of the gross domestic product, indicating that the ocean is becoming an integral part of the economy. However, marine development still faces many problems, such as climate change, damage to the marine environment, water shortage, and depletion of marine resources, which seriously affect the development of marine economy [20–24]. Among them, the connection between marine resources and marine economy is the closest and has become the focus of the scholars' research [25].

Scholars have discussed the relationship between marine resources and the marine economy from different perspectives. Marine economic development requires the input of marine resources as support [7]; thus, the research direction has mainly been developed with marine resource input as the explanatory variable and marine economic development as the explained variable. For example, Kiran et al. [8] note that the ability to maximize the use of marine fishery resources will enable Pakistan to have a voice in domestic and international markets, thereby leading to the economic development of the country. Similarly, Odeku [9] argues that intensively developing and utilizing South Africa's rich marine resources will foster tremendous economic growth.

However, due to resource constraints, the actual rate of economic growth has been slower than expected. Nordhaus [26], who uses the term "growth dampening" to refer to the extent to which resource constraints reduce economic growth, compares neoclassical growth models with and without resource constraints to measure natural resources' resistance to economic growth in the US. Bruvoll et al. [27] measure the welfare loss in Norway caused by environmental "damping". Based on an analysis of the impact of energy shortages on US economic growth, Uri [28] reports that crude oil shortages had a significant impact on US economic growth from 1889 to 1992. In summary, resource constraints are an obstacle to economic growth. With the rapid development of China's marine economy and marine resources, the depletion of marine resources, environmental pollution of near-shore waters, and other problems are becoming increasingly prominent. Further, the role of the use of marine resources in promoting the marine economy has gradually diminished, and the conditions of the factors supporting marine economic development have also undergone profound changes. As a result, countries worldwide are actively exploring other influencing factors to promote marine economic development.

The views scholars hold on the impact that capital inflows will have on the economy can be broadly divided into two types. The first view is that capital inflows have a positive impact on economic development. Agbloyor et al. [29] establish that short-term capital inflows boost economic growth; however, this positive boost is only evident when the financial markets of the inflowing countries are sufficiently strong. Butkiewicz and Yanikkaya [30] argue that long-term capital inflows also have a catalytic effect on economic development, while limiting capital inflows reduces that effect. The second view considers capital inflows' possible negative macroeconomic impact. Lensink and Morrissey [31] argue that capital inflows can only promote smooth economic growth if they remain stable over time (i.e., fluctuations in capital inflows can have a direct negative impact on economic growth). Currently, only the first research view exists in the discourse on marine economy. Capital inflow can directly promote the renewal of various machines and equipment within marine enterprises, as well as the construction of various infrastructures to improve operational efficiency and bring about greater marine economic growth. In addition, the inflow of capital will attract more talents, and the progress of science and technology, enterprise management, and so on are inseparable from the talents. Rashid et al. [12] note that marine economic growth requires adequate marine capital, which reveals the important role of capital investment in marine economic development.

In addition to capital, labor also has an impact on the economy. Boadi et al. [32] posit that the labor force will contribute to economic growth, and low-income countries should focus on upgrading their labor force through education. Alemeu [33] reports that labor also contributes to growth in African regions where economic growth has been unstable. Can [34] expands on previous research and determined that increases in the female labor force following the repeal of laws that discriminate against women also lead to economic growth. However, Balog [35], in analyzing the relationship between the labor force and economic growth in European countries, determined that the labor force does not accelerate economic growth. For the marine economy, van Lottum and van Zanden [13] determined that the input of high-quality labor increases rapid marine economic growth. Radhakrishnan et al. [16] note that the marine fishery industry's significant contribution to economic development is not only dependent on technological advances in fisheries, but is also influenced by labor wages.

Science and technology are the first driving force toward leading development. Pandiloska [36] states that technology is a key factor in promoting economic growth and improving firms' competitiveness in the business world, and that more innovation from technology-intensive firms will lead to more new markets, which will contribute to economic growth. The same holds true for the marine economy. Liang and Choi [17] state that marine technology improvement is an important factor in the growth of China's marine economy, while Kiyong and Cho [14] argue that advances in marine science and technology can provide new growth drivers for marine economic development.

The literature review determined that capital, labor, and science and technology investments are able to promote economic growth. Some scholars have considered resource shortages, but only on one aspect, and have not considered resource constraints in conjunction with the inputs of factors, much less focusing the field on the marine economy. For example, Bringezu [37] notes that countries experiencing natural resource shortages can rely on technological advances to overcome them and promote economic growth. Managi et al. [38] also posit that the impact of technological innovation can fully offset the impact of resource scarcity. Bringezu et al. [39] argue that technology is the basis for increasing resource productivity to break the link between resource consumption and economic growth. These previous findings suggest the possibility that enhancing technological capabilities could promote marine economic growth even under marine resource constraints. However, if so, the impact that capital and labor would have on the marine economy, given these constraints, is unclear. To address these issues, this study classifies marine resources according to their resource industry types, precisely explores the relationship between marine resources and economic growth, and fully considers the interactions between capital, labor, and technology and marine resources, and constructs threshold effect models as threshold variables.

The remainder of the paper is organized as follows. Section 3 describes the construction of the empirical model, variables and data, and statistical analysis methods. Section 4 presents an empirical analysis using a fixed-effects model to test the impact of marine resources on marine economic growth, using capital, labor, and technology as control variables, which are then regressed as threshold variables to further investigate the mechanism of action and change characteristics of the control variables as well as marine resource inputs on the marine economic growth process under the marine resource constraint. Section 5 summarizes relevant findings based on the study's results and proposes relevant policy recommendations to promote marine economic growth.

3. Model, Data, and Variables

We establish the equation for the relationship between marine resource inputs and the impact of marine economic growth, as shown in Equation (1):

$$\ln GOP_{it} = \sigma_{it} + \alpha_1 \ln MR_{it} + \Sigma X_{it} + \theta_{it} + \varepsilon_{it} \tag{1}$$

Considering the possible non-linear relationship between marine resource input and marine economic growth, the squared term of marine resource input is introduced here to reflect it. The specific model is shown in Equation (2):

$$\ln GOP_{it} = \sigma_{it} + \alpha_1 \ln MR_{it} + \alpha_2 \ln MRit^2 + \Sigma X_{it} + \theta_{it} + \varepsilon_{it} \tag{2}$$

GOP is the level of marine economic growth expressed by regional gross marine product. Data were obtained from the Chinese Marine Statistical Yearbook; *MR* is the input of marine resources; *X* is the control variable, including the inputs of marine capital (*MC*), marine-related labor (*ML*), and marine science and technology (*MT*); σ_{it} represents the intercept term; θ_{it} represents the time dummy variable in coastal areas; ε_{it} is the regression disturbance term; and i, t represent province and year, respectively. All variables are logarithmically treated. Each indicator is explained below.

MR represents the amount of marine resource input, which includes living and non-living resources. The paper refers to the classification of environmental assets in the SEEA central framework and the division of the three industries to classify marine resources according to the main industries to which they are applied. The primary industry refers to the industries that produce natural objects. Based on the availability of data, we select the amount of seawater harvesting and mariculture to constitute the primary industry in the ocean. The secondary industry is the processing and manufacturing industry, and we choose marine crude oil production, marine natural gas production, sea salt production, marine chemical production and marine mining production to represent the secondary industry. The tertiary industry mainly refers to transportation, public services and other non-material production sectors, and we choose marine transportation volume to represent them. Please refer to Table 1 for details.

Data were obtained from the Chinese Marine Statistical Yearbook. Different industries involve different types of resources and cannot be summed up directly in an exhaustive manner. The entropy method can exclude the interference of human factors as much as possible, and can also overcome the problems such as difficulties in analysis caused by the small variability of the selected index values, and thus can more scientifically dig out the information implied by the data. Therefore, this paper adopts the entropy value method to synthesize indicators for three types of industrial resource inputs to obtain MR1, MR2 and MR3 in turn, and the main steps are as follows.

(1) Standardization processing. In order to eliminate the influence of data outline quantity, the raw data of each indicator in the evaluation index system are standardized. The data in the evaluation index system are the panel data containing m provinces, n indicators, and T years. The standardization formulas of positive and negative indicators are shown in Equation (3).

Table 1. Marine Resources Classification.

Industry Classification	Resource Statistics
Primary industry (MR1)	Marine fishing production, mariculture production
Secondary industry (MR2)	Marine crude oil, marine natural gas, sea salt, marine chemical, and marine mining production
Tertiary industry (MR3)	Marine transportation volume

$$X_{tij} = \begin{cases} \frac{x_{tij} - \min(x_j)}{\max(x_j) - \min(x_j)} + 10^{-3} \\ \frac{\max(x_j) - x_{tij}}{\max(x_j) - \min(x_j)} + 10^{-3} \end{cases}, \tag{3}$$

where X_{tij} denotes the standardized value ($t = 1, \ldots, T$; $i = 1, \ldots, m$; $j = 1, \ldots, n$); x_{tij} denotes the original value of the jth indicator in province i in year t; $\max(x_j)$ and $\min(x_j)$ are the maximum and minimum values of indicator j in all provinces in all years, respectively.

(2) The indicators are normalized.

$$w_{tij} = X_{tij} / \sum_{t=1}^{T} \sum_{i=1}^{m} X_{tij}, \tag{4}$$

where w_{tij} denotes the share of the jth indicator of the ith province in year t to the sum of the indicators of all provinces in all years.

(3) Calculate the information entropy of the jth indicator.

$$e_j = -(\ln mT)^{-1} \sum_{i=1}^{n} w_{ij} \ln(w_{ij}), \tag{5}$$

where m is the number of provinces in the study sample and T is the time span.

(4) Calculate the coefficient of variation for each indicator.

$$g_j = 1 - e_j. \tag{6}$$

(5) The weights of each indicator were calculated, and the index H_{ti} of the amount of resource input in the three types of industries in 11 coastal provinces and cities in China during 2006–2019 was calculated based on the weights.

$$W_j = g_j / \sum_{j=1}^{n} g_j, \tag{7}$$

$$H_{ti} = \sum_{j=1}^{n} W_j X_{tij}. \tag{8}$$

MC represents the volume of marine capital input measured using the volume of investment in marine fixed assets [40,41]. Data were obtained from the Chinese Statistical Yearbook. Many methods are available to measure the amount of investment in marine fixed assets, and we use the amount of investment in fixed assets within each region to determine it indirectly. The investment in marine capital can provide sufficient physical capital guarantee for scientifically controlling the amount of existing resource development and actively expanding the scale of resource development. Therefore, the prediction coefficient of this indicator is positive.

ML is the amount of marine labor input based on data from the China Marine Statistical Yearbook. The number of sea-related employed persons in each province and city is obtained from 2006–2016 due to the change in data statistical path; the number of employed persons in coastal areas is obtained from 2017–2019 and processed by a logarithm. In the early days of marine development, China had a large marine resource supply and labor force, which could be better utilized for economic development. However, owing to the increasing scarcity of marine resources, a large amount of human input will increase the burden of economic development, thereby leading to wasted resources. In addition, if human input exceeds the demand for marine resources, it will lead to higher development costs and less efficient resource use, which is detrimental to improving the economic contribution of resources. Based on the above analysis, the prognostic coefficient of this indicator cannot be determined.

MT is the amount of marine science and technology input expressed by the total funding income of marine research institutions; data obtained from the China Marine Statistical Yearbook. The level of marine science and technology determines the efficiency of a country's exploitation of marine resources and is an important driving factor of marine economic growth. With increased technology investment, the traditional rough resource development mode is changing, the way resources are utilized is constantly updated, and the efficiency of resource use has greatly improved. However, overexploiting resources will hinder the sustainability of resource input to marine economic growth, especially excessive and disorderly development, which is highly likely to damage the resource environment, such as a decline in or even the extinction of biological resources and reduced quality of tourist resource attractions. Based on the above considerations, the prognostic coefficient for this indicator is also undetermined.

Table 2 shows the results of the descriptive statistical analysis conducted for each of the main variables of the overall sample in the model.

Table 2. Descriptive statistics of the variables.

Variable	Sample Size	Mean	Standard Deviation	Minimum	Maximum	Predicted Coefficient Symbol
LnMGOP	154	8.086621	0.960218	5.706113	9.869186	/
LnMR1	154	15.89831	0.1240218	15.55705	16.10493	+
LnMR2	154	13.09142	1.443139	8.768588	15.40981	+
LnMR3	154	9.466966	0.975403	6.364751	11.33257	+
LnMC	154	9.366622	0.9943723	6.049498	10.98608	+
LnML	154	5.963339	1.144615	4.400603	8.788837	?
LnMT	154	13.19514	1.598125	8.304	15.23491	?

4. Results and Discussion

4.1. Regression Analysis of the Fixed Effects Model of MR and MGOP

We use a fixed-effects model to make a preliminary judgment on the relationship between marine resources (*MR*) and marine economic growth (*MGOP*). Table 3 shows the results of this test. Rˆ2 is the coefficient of determination which indicates the proportion of the variation in Y that can be explained by the variation in X. It is a measure of how closely the regression line fits each observation. When Rˆ2 = 1, it indicates a perfect fit; when Rˆ2 = 0, it indicates that there is no linear relationship between X and Y. The higher the value of Rˆ2, the better the fit. In this paper, Rˆ2 is all close to 1, which indicates a good fit and a linear relationship. F is used to test whether the regression relationship is significant or not. This paper takes $p < 0.10$ as more significant, $p < 0.05$ as significant, and

$p < 0.01$ as very significant. All models in this paper passed the F-test and all regression relationships were significant.

Table 3. Test results of the relationship between marine resources and economic growth (explained variable: marine economic growth).

Variable	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
LnMR1	7.555 *** (0.00)			6.525 *** (0.00)		
LnMR1ˆ2				0.043 *** (0.00)		
LnMR2		0.054 ** (0.03)			−0.437 * (0.08)	
LnMR2ˆ2					0.021 ** (0.05)	
LnMR3			0.155 *** (0.00)			0.226 *** (0.00)
LnMR3ˆ2						0.015 *** (0.00)
LnMC	0.009 (0.61)	0.486 *** (0.00)	0.441 *** (0.00)	0.015 (0.21)	0.484 *** (0.00)	0.387 *** (0.00)
LnML	0.014 ** (0.02)	0.086 *** (0.00)	0.073 *** (0.00)	0.006 (0.19)	0.088 *** (0.00)	0.039 ** (0.01)
LnMT	−0.005 (0.47)	0.099 *** (0.00)	0.084 *** (0.00)	−0.015 *** (0.00)	0.099 *** (0.00)	0.031 (0.10)
Cons	−112.128 *** (0.00)	1.013 *** (0.01)	0.952 *** (0.00)	−106.405 *** (0.00)	3.872 ** (0.01)	0.306 (0.31)
Obs	154	154	154	154	154	154
R^2	0.985	0.871	0.874	0.993	0.875	0.908
F	7.58	53.82	52.19	27.12	54.93	74.57
p	0.000	0.000	0.000	0.000	0.000	0.000

Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively; *p*-values are in parentheses.

As Table 3 demonstrates, the coefficients of *MR1* and *MGOP* are significantly positive, indicating that an increase in marine resource input in the primary industry can indeed promote marine economic development. Meanwhile, the coefficients of LnMC and LnMT are insignificant, and the coefficient of LnML is significantly positive. This may be due to the fact that the primary industry is mostly resource-dependent with living marine resources, and marine resources have a constraining effect on the growth of marine economy in this industry, and the primary industry does not need the support of capital and technology, etc., and only labor is needed to drive the growth of marine economy. The regression coefficients of *MR3* and *MGOP* are significantly positive, indicating that an increase in marine resource input in the tertiary sector can also promote marine economic development. Over time, the tertiary industry accounts for an increasing proportion of the gross marine product, of which the development of marine transportation is based on resources; thus, the relationship between the two roles is easily apparent. The regression coefficient of *MR2* and *MGOP* is also significantly positive; however, its contribution is smaller than those of the coefficients of primary and tertiary marine resource inputs and marine economic growth. We posit that this is because the growth of the secondary marine economy will be influenced by various factors, with marine resources being only one of the factor inputs, and that the input–output effect may be disturbed by other factors. The control variables *MC*, *ML*, and *MT* showed mostly facilitative effects for *MGOP*.

In addition, we introduce the squared term of marine resources, and the above results show that *MR* and *MGOP* display a U-shaped relationship curve. Thus, regarding factors that lead to change in the marginal growth effect of *MR* on *MGOP*, considering the interaction of factors in economic growth, we defined such influences as the inputs of capital, labor, and technology. Subsequently, we use these three as threshold variables and build a threshold effect model to verify whether the nonlinear effects of the three elements hold.

4.2. Threshold Effect Test for MR and MGOP

In this study, we adopt Hansen's [42] threshold model with marine input capital, sea-related employment, and marine science and technology in coastal areas as threshold variables and conduct threshold tests under the assumptions of single and double thresholds, as shown in Equation (3). The threshold test is employed to verify whether the threshold effect exists and the threshold value is significant, by which a conclusion can be drawn as to whether there is a nonlinear relationship between the variables. Taking the significance test of the single threshold model as an example, the original and alternative hypotheses for the threshold effect are $H_0 : \beta_1 = \beta_2$ and $H_1 : \beta_1 \neq \beta_2$, respectively. The original hypothesis states that no threshold effect is present in the tested model, and that if the results reject this hypothesis, a threshold effect exists. Thus, Equation (9) is composed as follows:

$$\begin{cases} \ln GOP_{xit} = \eta_\iota + \theta_1'(\sigma_{it} + \sum X_{it} + \alpha_1 MR_{xit} \\ \times I(q_{it} \leq \gamma) + \alpha_1 MR_{xit} \times I(q_{it} > \gamma) + \theta_{it} \\ + \varepsilon_{it}) \\ \ln GOP_{xit} = \eta_\iota + \theta_1'(\sigma_{it} + \Sigma X_{it} + \alpha_1 MR_{xit} \\ \times I(q_{it} \leq \gamma_1) + \alpha_1 MR_{xit} \times I(\gamma_1 < q_{it} \leq \gamma_2) \\ + \alpha_1 MR_{xit} \times I(q_{it} > \gamma_2) + \theta_{it} + \varepsilon_{it}) \end{cases} \tag{9}$$

where $I(\cdot)$ represents the schematic function, which takes the value of 0 when the expression in parentheses is false and 1 when the opposite is true. σ_{it} are constants, θ_{it} and ε_{it} and are fixed effects and random perturbation terms, respectively. The threshold value γ divides the sample interval into two or three bins, and each bin is differentiated using the slope value α_x, respectively. φ_x is the impact coefficient of control variables, and X denotes the control variables, including marine capital input, labor input, and marine science and technology input.

Table 4 shows the results of the threshold tests for the existence of the relationship between marine resource inputs and economic growth in China from 2006 to 2019 for capital, labor, and technology. Table 4 reflects the F-values of the threshold tests for each variable and the *p*-values obtained by repeated sampling of 500 times according to the self-sampling (bootstrap) method.

Table 4. Marine resources and economic growth threshold test.

Explained Variable	Threshold Type	LnMC	LnML	LnMT
LnMR1	Single threshold value	50.69 **	84.19 ***	146.38 ***
	p-value	0.0220	0.0000	0.0000
	Double threshold value	27.64	36.56	29.44 *
	p-value	0.1040	0.1200	0.0620
LnMR2	Single threshold value	7.04	19.70 **	44.16 ***
	p-value	0.6080	0.0300	0.0000
	Double threshold value	9.85	8.90	40.38 ***
	p-value	0.1740	0.4400	0.0000
LnMR3	Single threshold value	4.56	19.63 *	47.13 ***
	p-value	0.8700	0.0620	0.0040
	Double threshold value	7.94	19.17 *	24.65 **
	p-value	0.2900	0.0980	0.0340
Number of bootstrap samples		500	500	500

Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively; *p*-values are in parentheses.

The results in Table 4 show that only *MR1* passes the threshold test when *MC* is used as the threshold variable at a bootstrap count of 500, indicating a lack of threshold effect of capital investment in secondary and tertiary marine resources and marine economic growth. Further, the regression results in Table 5 show that, for marine economic growth, marine capital investment can play a significant promoting role under both secondary and tertiary marine resource inputs.

Table 5. Interval division of the estimation result of the threshold value of marine resources and economic growth.

Variable	lnMC	lnML	lnMT
LnMR1$_{-0}$	LnMC $\leq$ 10.1771	LnML $\leq$ 4.8528	LnMT < 10.0048
	Low-value distribution area of marine capital	Low-value distribution area of the marine labor force	Low-value distribution area of marine technology
LnMR1$_{-1}$	LnMC > 10.1771	LnML > 4.8528	10.0048 $\leq$ LnMT < 11.4468
	High-value distribution area of marine capital	High-value distribution area of the marine labor force	Median distribution area of marine technology
LnMR1$_{-2}$			LnMT > 11.4468
			High-value distribution area of marine technology
LnMR2$_{-0}$		LnML $\leq$ 4.6022	LnMT < 12.1860
		Low-value distribution area of the marine labor force	Low-value distribution area of marine technology
LnMR2$_{-1}$		LnML > 4.6022	12.1860 $\leq$ LnMT < 14.0069
		High-value distribution area of the marine labor force	Median distribution area of marine technology
LnMR2$_{-2}$			LnMT > 14.0069
			High-value distribution area of marine technology
LnMR3$_{-0}$		LnML < 4.0622	LnMT < 12.1860
		Low-value distribution area of the marine labor force	Low-value distribution area of marine technology
LnMR3$_{-1}$		4.0622 $\leq$ LnML < 5.1636	12.1860 $\leq$ LnMT < 14.0069
		Median-value distribution area of the marine labor force	Median distribution area of marine technology
LnMR3$_{-2}$		LnML > 5.1636	LnMT > 14.0069
		High-value distribution area of the marine labor force	High-value distribution area of marine technology

The marine economy cannot be developed without investment in marine capital. The growth of China's marine economy is still in its infancy, and marine resource development is focused on coastal and offshore areas. Backward technology has caused the rough exploitation method to lead to problems such as marine pollution and biological resource decay. Marine capital investment is key to solving these issues. In addition, against the background of seizing the opportunity for marine development and striving to attain the commanding heights of marine development, the renewal of the marine economic growth model, the transformation of the traditional marine industry, and the cultivation of the emerging marine industry also require capital support. Therefore, the present empirical results are consistent with the reality that capital input can always promote economic development and no threshold effect is exerted on either secondary and tertiary marine resource input.

Subsequently, when *ML* is used as the threshold variable, *MR3* only passes the double threshold test, and *MR1* and *MR2* only pass the single threshold test. In contrast, when *MT* is used as the threshold variable, *MR1*, *MR2*, and *MR3* pass the double threshold. To facilitate this study, we divided the intervals according to the threshold estimates, as shown in Table 5.

4.3. Threshold Regression Analysis of MR and MGOP

The results of the threshold test indicate that changes in *MC*, *ML*, and *MT* input levels can have a phase effect on the relationship between *MR* and *MGOP*; however, the degree to which the elements affected and the magnitude of the effect still require further threshold regression to allow conclusions to be drawn. The results of the threshold regression are shown in Table 6.

Table 6. Regression results of thresholds for marine resources and economic growth.

	Marine Resources of the Primary Industry			**Marine Resources of the Secondary Industry**			**Marine Resources of the Tertiary Industry**		
Variable	**lnMC**	**lnML**	**lnMT**	**Variable**	**lnML**	**lnMT**	**Variable**	**lnML**	**lnMT**
LnMR1$_{-0}$	7.657 *** (0.00)	7.511 *** (0.00)	7.624 *** (0.00)	LnMR2$_{-0}$	0.086 *** (0.00)	0.058 *** (0.00)	LnMR3$_{-0}$	0.271 *** (0.00)	0.108 ** (0.02)
LnMR1$_{-1}$	7.664 *** (0.00)	7.500 *** (0.00)	7.612 *** (0.00)	LnMR2$_{-1}$	0.050 ** (0.04)	0.031 (0.12)	LnMR3$_{-1}$	0.203 *** (0.00)	0.076 * (0.10)
LnMR1$_{-2}$			7.605 *** (0.00)	LnMR2$_{-2}$		0.050 ** (0.01)	LnMR3$_{-2}$	0.230 *** (0.00)	0.103 ** (0.03)
LnMC	−0.021 (0.19)	0.023 (0.10)	0.020 * (0.09)	LnMC	0.484 *** (0.00)	0.425 *** (0.00)	LnMC	0.390 *** (0.00)	0.410 *** (0.00)
LnML	0.003 (0.61)	0.031 *** (0.00)	0.011 *** (0.00)	LnML	0.114 *** (0.00)	0.090 *** (0.00)	LnML	0.072 *** (0.00)	0.075 *** (0.00)
LnMT	−0.009 (0.14)	−0.001 (0.83)	0.030 *** (0.00)	LnMT	0.105 *** (0.00)	0.145 *** (0.00)	LnMT	0.083 *** (0.00)	0.119 *** (0.00)
C	−113.374 *** (0.00)	−111.564 *** (0.00)	−113.491 *** (0.00)	C	0.799 ** (0.03)	1.048 *** (0.00)	C	0.753 ** (0.01)	1.313 *** (0.00)
R^2	0.989	0.991	0.994	R^2	0.887	0.924	R^2	0.903	0.920
F	10.40 ***	12.00 ***	12.59 ***	F	62.84 ***	92.01 ***	F	54.04 ***	85.96 ***

Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively; t-values are in parentheses.

As presented in Table 6, when *MC* is used as the threshold variable, a single threshold effect is exerted on the *MR*–*MGOP* relationship for the primary sector only. Regarding the low-value distribution of marine capital, the input of *MC* significantly enhances the effect of *MR*. This enhancement effect is greater when the *MC* input is continuously increased until it enters the high-value distribution area of marine capital. In general, as in the secondary and tertiary sectors, a clear path dependence of marine economic growth on marine capital investment can be observed. None of the control variables are significant, indicating that when capital input is used as the threshold variable, the growth of the marine economy under the primary sector does not require the support of technology and labor.

When *ML* is used as the threshold variable, a single threshold effect is exerted on the relationship between *MR* and *MGOP* for the primary and secondary industries. Regarding the development of the primary and secondary industries of the marine economy, when *ML* is in the low-value distribution area of marine labor, resource input can significantly promote marine economic growth, and when *ML* enters the high-value distribution area of marine labor, the promotion effect becomes relatively smaller but is still statistically significant. Within the appropriate scope, labor input can enable effective exploitation of marine resources and promote marine economic development. However, when labor input is excessive, especially in the form of the influx of low-quality labor, it will cause resource exploitation to become disorderly and barbaric, causing serious environmental damage to and reducing the level of sustainability of economic growth. Nevertheless, excessive labor input will greatly increase the cost of resource utilization and inhibit the growth dynamics of the marine economy. Meanwhile, the coefficients of both *MC* and *MT* are insignificant, which this paper suggests is because the growth of the secondary marine economy can be affected by a variety of factors, weakening the role of other factors when labor input is used as the threshold variable.

In addition, we note that *ML*'s entry into the high-value distribution area of the marine labor force significantly drives the relationship between industries more in the primary industry than in the secondary industry. In analyzing the reasons, we posit that this is mainly because the primary marine industry is still dominated by traditional fishing, which is labor-intensive. Factors such as the backwardness of technical tools and restrictive geographical environment mean that relying on a large number of laborers remains necessary to exploit marine resources. Compared to the primary industry, the development of the secondary industry of the marine economy is mainly based on manufacturing, although the traditional industries are predominant. However, the structure of China's manufacturing industry is undergoing a transformation and upgrades, and compared with the primary industry, labor dependence is reduced. Therefore, when considering the contribution of *ML* to *MR*, we find that the impact of the primary industry is more significant than that of the secondary one. Similarly, the secondary industry will be affected more when labor is over-invested; therefore, the promotion effect of *ML* will become significantly smaller when it enters the high-value distribution area of marine labor.

Further, a double threshold effect is exerted on the relationship between *MR* and *MGOP* in the tertiary industry when *ML* is used as a threshold variable. In the low-value distribution of marine labor, the *ML* input significantly enhances the effect of *MR*. When the *MT* input is continuously increased until it enters the medium-value distribution of marine labor, the enhancement effect will be weakened. However, when it enters the high-value distribution of marine labor, the enhancement effect increases again, although it remains lower than at the initial level. Based on our analysis, we posit that this is because the tertiary industry mainly functions from within the service sector, which is inherently inseparable from the support of labor force. However, the service industry focuses not only on the quantity of labor but also on the quality. When too much labor is imported at once, it is inevitable that low-quality labor will exist, which will impact the growth of the marine economy. When the labor force continues to increase, the market tends to be saturated with the best workers, and a high-quality labor force will further serve the market, which in turn will contribute to marine economic growth. The original research results only tell us that labor input will promote the growth of marine economy. However, due to the current marine resource constraints, our study proves that labor input should be appropriate, and when labor input is excessive, it will instead affect the dynamics of marine economic growth.

When *MT* is used as the threshold variable, a double-threshold effect of scientific and technological inputs on the impact of marine resources on marine economic growth occurs. In the development of the primary industry of the marine economy, when *MT* is in the low-value distribution area of marine science and technology, resource input can promote marine economic growth. When *MT* input is increased until it enters the median-value distribution area of marine science and technology, the enhancement effect is weakened. Further, when it enters the high-value distribution area of marine science and technology, the enhancement effect is further weakened; however, it always displays a significant promotion effect. The primary industry of the marine economy remains dominated by the traditional fishing industry. Although scientific and technological progress will promote marine economy, it still mainly relies on labor, and when investments in science and technology increases, it also consumes capital. To ensure balance between capital inflow and outflow, it is necessary to reduce labor expenditure, which will weaken its promotional role.

Regarding the development of the second and third industries of the marine economy, when *MT* is in the low-value distribution area of marine science and technology, resource input can significantly promote marine economic growth. When *MT* input is increased until it enters the middle-value distribution area of marine science and technology, the promotion effect is weakened. When it enters the high-value distribution area of marine science and technology, the promotion effect increases again, and becomes equal to its initial value. Extensive research and development of new technologies, applied in the field of marine resources, can explore new use values of marine resources, optimize the development mode of marine resources, rationalize the use of marine resources, and improve the use efficiency of resources. Thus, marine resource development in this stage will significantly promote marine economic development. Although technological innovation has increased the strength and depth of resource development, marine resources are finite, and excessive development will gradually weaken the role of technology in driving economic growth, which is not conducive to sustainable economic development. When people realize this, they will focus more on the quality of technology development and its adaptation to all resources along with technological innovation, and in turn, marine resource development will further promote marine economic development. Compared with the results of the original study, we have also made progress in science and technology investment. It is not just a matter of investing in science and technology to maximize the growth of the marine economy, but rather of paying attention to the adaptation of technology to resources and of fully considering the current economic conditions.

Regarding the control variables, we have explained separately for the insignificant cases and for the remaining cases the coefficients are positive and all of them pass the significance test. This is the same result as those of the existing studies, where the inputs of capital, labor and technology are able to promote the growth of the marine economy.

5. Conclusions and Policy Recommendations

In this study, we analyze the relationship between marine resources and economic growth across 11 coastal provinces and cities. Considering the interactions between marine production factors, we posit that marine resources and economic growth do not share a simple linear relationship and may be influenced by other factor inputs. The regression and threshold effect models confirm the validity of the idea that marine resources and economic growth will result in different phases under different levels of marine capital, sea-related labor, and marine science and technology inputs. We conclude the following: The impact of marine resources on economic growth has a single threshold effect of capital input only in the primary industry marine resources. Still, in general, with the increase in capital input, the maritime economy shows a positive development trend. There is a single threshold effect of labor input in the primary and secondary industry marine resources for marine economic growth, and a double threshold effect in the tertiary industry marine resources. With the investment of marine science and technology, the driving result of the development and utilization of marine resources in the first, second and third industries on economic growth generally shows a development law of first large, then small, and then large.

This study's empirical results indicate that the development of the marine economy requires significant capital investment. Currently, there exists a wide capital gap for China's marine development, especially with respect to monetary capital. Financial capital is the main driving force of marine development, and its supporting role is mostly manifested across various levels, such as marine resource development, marine equipment renewal, and marine technology change. Starting from the successful experience of international and domestic capital support for industrial development, based on this study's findings, we propose the establishment of various funding models, such as private investment, credit market, and foreign investment, to provide long-term, stable financial support for developing China's marine resources. Construction funding should be strengthened at all levels and various specific marine funds should be created to meet the varying resource needs of different marine industries. However, to solve the hindrances in the development of financing bottlenecks and constraints, encouraging private capital investment in the marine sector necessitates the employment of various methods, which will require coastal governments at all levels to increase efforts to improve their service environment and approval conditions and provide financial subsidies for key marine development projects to reduce their investment costs. Simultaneously, the establishment of a sound capital market plays an important role in allocating China's marine resources, promoting the development of marine science and technology, optimizing the structure of the marine industry, and preventing financial risks.

In addition, improving workforce quality is crucial. This study's results show that China continues to implement a labor-based approach to marine economic development. China has a large population, a long coastline, and abundant marine resources, which are the root causes for the rapid development of China's marine economy in recent years. However, from a theoretical perspective, excessive labor input will lead to not only a decrease in the efficiency of resource utilization but also an increase in enterprises' production costs, which is detrimental to marine economic development. In considering the ways to address the negative effects of the large workforce on the economy, improving the quality of the workforce and attaching importance to talent training are effective methods for solving this problem. In the development of China's marine industries, especially the emerging marine industry and high-tech-oriented marine industry, the size of their potential depends on training talent. To cultivate marine talent and improve the quality of marine labor force, we must strengthen marine education, improve the quality and structure of the marine labor force, and promote the full employment of the marine labor force. Countermeasures should be taken, including establishing a sound marine education curriculum system from elementary school to university to cultivate professional and technical marine talent, and further improving the continuing education and re-education system for those employed in marine industries to enhance their professionalism, strengthening exchanges between research institutes and marine colleges and universities to promote positive interaction between marine industries and the working population, and actively introducing marine talent from abroad.

Finally, increased investment in marine science and technology is needed. Marine science and technology innovation is the key to promoting marine economic development and transforming the marine economy to one that is conservation-oriented, green, and coordinated. At the beginning of the 21st century, Chinese marine science and technology has made great progress in the context of national marine strategy and internationalization; however, there is still substantial room for development. The results of this paper show that we should not only improve the technology level, but also pay attention to improve the innovation ability of marine science and technology and the matching degree of technology with the available resources so as to promote the development of marine economy to the greatest extent possible. To improve China's marine science and technology innovation capacity, it is first necessary to increase basic investment in science and technology innovation and support the leading role of high-end marine research and development platforms, including establishing locations such as national marine laboratories and engineering research centers. In addition, it is necessary to actively seek government policy support and patent protection. We further suggest actively introducing foreign enterprises to participate in fair competition in the domestic market and promoting China's sea-related enterprises to increase progress in technological innovations, while also further enhancing the transformation rate of China's marine science and technology achievements. Further, we also suggest promoting the integration of government, industry, academia, and research, and encouraging the agglomeration of marine industries to form a complete industrial chain.

Since the neighboring countries have similar marine resources and climate conditions as China, the policy advice in terms of capital investment and science and technology investment is referable. The difference is that China has an abundant labor force, which other countries do not have, so further research is needed on the labor force to promote the development of marine economy. In addition, there are certain shortcomings in this paper. First, this paper does not put different industries into the same model, so it is not possible to compare the size of the impact of different industries on the marine economy under different circumstances, and further investigation is needed. Second, due to the availability of data, we only selected three non-stop threshold variables as control variables. If several more different control variables could be considered, more precise and meaningful results might be obtained.

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Carbon Neutrality Assessment and Driving Factor Analysis of China's Offshore Fishing Industry

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Abstract: The marine fishing industry has a huge carbon sink potential and is also an important source of carbon emissions. The low-carbon development of the marine fishing industry is particularly important. Based on the perspective of carbon neutrality, this study analyzed the trend of net carbon emissions, carbon emissions and carbon sinks in the offshore fishing industry in China and 11 coastal provinces from 2010 to 2019 and decomposed the driving factors of the net carbon emissions of the offshore fishing industry with the LMDI decomposition method. The results show the following: (1) China's offshore fishing industry is in a partially carbon-neutral state. Overall, the net carbon emissions have decreased, and the carbon neutrality capacity has improved. However, the net carbon emissions have increased since 2016. From 2010 to 2019, both the carbon emissions and carbon sinks of China's offshore fishing industry declined. Carbon emissions fluctuated at first and then declined rapidly, while carbon sinks rose slowly and then showed a significant downward trend. (2) The offshore fishing industry in coastal provinces is also in a state of partial carbon neutrality, and the trends of carbon emissions, carbon sinks and net carbon emissions in most provinces are consistent with the national trends, but there are large differences between regions. (3) For the whole country, among the driving factors of net carbon emissions in the offshore fishing industry, industrial development is the main positive driving factor, and population size is the main negative driving factor. The net carbon coefficient and energy intensity also play a certain role in driving net carbon emissions. (4) Population size is an important inhibitory factor for the net carbon emissions of the offshore fishing industry in most coastal provinces, and the driving direction of the net carbon coefficient, energy intensity and industrial development is inconsistent. Based on the above research, relevant suggestions are put forward for the green development of the marine fishing industry.

Keywords: marine fishing industry; carbon neutrality; carbon emissions; driving factors; LMDI decomposition method

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1. Introduction

Carbon sinks, through afforestation and vegetation restoration, reduce the concentration of carbon dioxide in the atmosphere. Biological carbon sinks in particular have the advantages of being safe, efficient and economically feasible [1] while contributing to the conservation of biodiversity. The development of biological carbon sinks has become an important way to achieve the goal of carbon neutrality and promote sustainable economic and social development. With the concepts of "ocean blue carbon" [2] and "carbon sink fishery" [3], the carbon sink function of fisheries has been emphasized. Fishery is considered as the only controllable and effective sink industry in the ecosystem [4], and the carbon sink potential is huge. On the other hand, fishery is an important part of large agriculture, and it generates considerable carbon emissions in parallel with its economic development. China is a large fishing country, and its marine fishing output ranks first in the world all the year round. In the face of severe pressure on fishery resources and the environmental carrying capacity of fisheries, the sustainable development of marine fisheries and carbon neutrality have become inevitable.

As an important part of the fishery industry, the marine fishing industry provides rich aquatic products and makes important contributions to maintaining food security, in-creasing fishermen's incomes and promoting the development of coastal areas. The marine fishing industry is a carbon sink fishery, mainly through biological pumps that sequester carbon and move carbon out of the water body so as to achieve the carbon sink function. Marine plants use carbon dioxide for photosynthesis to convert inorganic carbon into organic carbon and transfer energy through the food chain or food web, and part of the marine organisms is harvested and used by humans in the form of catch to achieve "carbon transfer" [5].

The marine fishing industry is highly dependent on energy [6], accounting for more than 70% of fishery energy consumption. The energy consumption per unit output value is far higher than that of the primary industry. The energy consumption per ton of the marine fishing industry in China is also higher than that of other advanced countries [7]. The fuel consumption of fishing vessels has become an important source of carbon emissions. Therefore, the marine fishing industry has the dual attributes of "carbon source" and "carbon sink", and it is necessary to examine the changes of carbon emissions and carbon sinks in the marine fishing industry from the perspective of carbon neutrality. Identifying the drivers of carbon neutral capacity changes and analyzing their contribution effects can help us understand the impact of each factor on carbon neutral capacity improvement, which is important for better guiding the low-carbon development of China's marine fisheries.

This study makes the following contributions. First, on the basis of the assessment of carbon emissions and carbon sinks, the net carbon emissions were calculated and the changes in the carbon neutral level of China's offshore fishing industry were analyzed. Secondly, the trophic level method was used to estimate the carbon sink of the offshore fishing industry, taking into account the energy transfer efficiency in the food chain. Thirdly, the LMDI decomposition method was used to analyze the contribution effects of each driving factor to the net carbon emissions from the offshore fishing industry. In theory, differently from the previous studies that only focused on carbon emissions, this study evaluated the carbon sinks of the offshore fishing industry, which enriches the relevant studies of the marine fishing industry and carbon sinks. The contribution of each factor was found through the LMDI decomposition, which provided a theoretical reference for the development of the offshore fishing industry. The practical significance is that the study emphasizes the ecological function of the offshore fishing industry, proves the huge carbon sink potential of the offshore fishing industry, supports the emission reduction of the marine fishing industry and puts forward targeted suggestions.

2. Literature Review

There are few studies on the carbon emissions and carbon sink changes of the marine fishing industry from the perspective of carbon neutrality, most of which study the carbon changes of the marine fishing industry from the single perspective of carbon emissions or carbon sink. Commercial fisheries are highly dependent on fossil fuels, exacerbating air pollution and greenhouse gas emissions [8–12]. Greer et al. emphasized the potential importance of marine fishing as a part of the global CO_2 emission reduction strategy by estimating the total carbon dioxide emissions and carbon emission intensity from global marine fishing fuel combustion from 1950 to 2016 [13]. China is a major country in marine fishing, and fishing vessels are an important source of energy consumption and carbon emissions [14–16]. The greenhouse gas emissions of Chinese fishing vessels account for about one-quarter of the total emissions of global fishing vessels [8]. Moreover, the greenhouse gas emissions of China's marine fishing industry show a steady growth trend [17]. The carbon emissions of the marine fishing industry are affected by fishing methods and fishing gear selection. Trawling and gill nets are high-emission fishing methods, and the energy consumption and carbon emissions of fishing vessels can be reduced by upgrading fishing vessels and strengthening the management of fishing operations [17,18]. Kristófersson et al. found that overall catches and abundance are the most important factors affecting fishery carbon emissions [19]. The seasonal fishing ban policy can also reduce greenhouse gas emissions [12].

In terms of carbon sinks, studies have found that marine animals play an important role in marine carbon storage. Reconstructing whales can remove 160,000 t of carbon from the atmosphere every year, which is equivalent to protecting 843 hectares of forest [20]; 12,000 sperm whales can remove a net 200,000 t of carbon from the atmosphere to the deep sea each year [21]. Gao et al. stated that carbon sink fishery has huge carbon sink potential. The global carbon sinks of fishery aquaculture and fish catching were 2,270,000–3,160,000 and 2,370,000–3,160,000 tons, respectively. Carbon sink fishery can become an important source of China's carbon sink growth potential in the future [22]. Liu et al. proposed an evaluation framework and accounting method for ocean carbon sinks that comprehensively considers the types of carbon sinks and their characteristic storage cycle timescales [23]. Yang et al. integrated the particulate organic carbon (POC) and dissolved organic carbon (DOC) released by shellfish and algae into the dissolved organic carbon sink measurement model and found that the regional carbon sink differences were significant in China's marine fisheries in 2020 [24]. The marine fishing industry removes higher trophic level marine organisms from the water body through fishing and harvesting, forming a fishery carbon sink [1]. Zhang et al. calculated the carbon sequestration of China's fishery industry in the Yellow Sea and Bohai Sea, and the annual carbon sequestration from 1980 to 2000, was 3,610,000–26,130,000 and 2,830,000–10,080,000 tons, respectively. Overfishing reduced the nutrient level of the catch, leading to a maximum reduction of 23% and 27% of the annual carbon sequestration. Therefore, resource-conservation fishery should be developed [25]. By establishing an overall assessment model and a sub-species assessment model, Yue et al. calculated that the average carbon sinks of China's Indian Ocean tuna fishery were 541,300 and 550,500 t, respectively [26].

In terms of the research on the influencing factors of carbon changes, scholars have used the STIRPAT model, the SDA model, the LMDI model and other methods to enrich the exploration in many fields [27–29]. In the field of marine fisheries, the LMDI decomposition method based on Kaya identity is mostly used to analyze carbon emissions. From the perspective of marine fisheries as a whole, some scholars focus on the driving effect of industrial scale, energy intensity, economic development, technological progress and other factors on carbon emissions or implied carbon emissions [30–32]. Some scholars have also focused on the effects of structure, scale and carbon ratio coefficient on the carbon sequestration capacity of mariculture [33,34]. Wang and Wang found through LMDI decomposition model analysis that carbon intensity is the main contributor of carbon emission reduction and the decoupling process of the marine fishing industry, and industrial structure is the main inhibiting factor of carbon emission reduction [35]. For pelagic fishing, the carbon emission intensity corresponds to the carbon decoupling state of the industry's economic growth. Scale and industrial structure factors have a strong driving effect on carbon emissions. Therefore, promoting equipment upgrading, accelerating the construction of overseas bases and building a long-term mechanism for energy conservation and emission reduction have become important measures for the low-carbon development of pelagic fishing [36]. With the proposed goal of carbon neutrality, scholars began to analyze the contribution effects of various driving factors on the net carbon emissions of marine fisheries and suggested that carbon intensity, industrial structure and industrial scale were important driving factors [37,38].

In summary, abundant achievements have been made in the study of carbon emissions from marine fisheries. Scholars have reached a consensus that the fuel consumption of marine fishing vessels is the main carbon emission source of marine fisheries, which lays a solid foundation for further research on carbon emissions from marine fisheries. However, the research on the carbon sink of marine fishery is still in the development stage, and few scholars have conducted preliminary exploration, lacking systematic analysis. The research on the development of China's marine fishing industry from the perspective of carbon neutrality is rare. The analysis of the driving factors of carbon neutrality in the marine fishing industry can help to find the deficiencies in the low-carbon development of the marine fishing industry, so as to formulate energy-saving and emission reduction measures. However, most of the existing studies are from the perspective of marine fisheries as a whole, and there is a lack of special research on the marine fishing industry, a high energy consumption sector. In addition, the existing studies on the influencing factors of carbon change are mostly based on carbon emissions, ignoring the marine capture carbon sink, which is not conducive to promoting the overall level of carbon neutrality in fisheries.

This study took the offshore fishing industry, a typical marine fishing industry, as the research object. Based on the existing research, this study focused on the carbon emissions and carbon sinks of the marine fishing industry from the perspective of carbon neutrality, evaluated the carbon neutrality capacity of the offshore fishing industry in China and 11 coastal provinces (except Hong Kong, Macao and Taiwan) from 2010 to 2019 and analyzed the dynamic change trend. The LMDI decomposition method was used in this study to decompose the driving factors of carbon neutrality change in the offshore fishing industry, in order to gain a deeper understanding of carbon-related changes in the marine fishing industry and provide a reference for the low-carbon development, energy conservation and emission reduction of the marine fishing industry.

3. Methods and Data Sources

The marine fishing industry can be divided into offshore fishing and pelagic fishing. Most of the existing studies take them as a whole, but the characteristics of resources and environment they face are very different. Taking them as a whole diminishes the characteristics between different production departments, which is not conducive to discovering the problems existing in each production department and leads to difficulty in making targeted decisions. In addition, the policies adopted for offshore fishing and pelagic fishing are different, emphasizing the control of offshore fishing and the development of pelagic fishing. For offshore fishing, due to marine environmental pollution and overfishing, China's offshore fishery resources are facing depletion. Therefore, China has introduced a series of management measures, such as the summer fishing moratorium system, and the "zero growth" and "negative growth" system of marine fishing output. As for pelagic fisheries, it is an important direction for China's marine fishing industry to emphasize the standardized and orderly development of pelagic fisheries and participate in the development of international fishery resources.

In China, the output of offshore fishing accounts for a large proportion of the total output of marine fishing, and the proportion of fishing vessels owned at the end of the year is high. In 2019, for example, the output of offshore fishing in China was 10,001,515 tons, accounting for 82.17% of the total output of marine fishing. The power of marine fishing motor boats in offshore fishing reached 10.7003 million kW, accounting for 78.98% of the total power of marine fishing motor boats. Whether it is the output of catch or the input of fishing vessels, the offshore fishing industry can suitably reflect the general level of the development of China's marine fishing industry. Therefore, this study took the offshore fishery as the research object.

3.1. Assessment of Carbon Neutrality in Marine Fisheries

According to the definition of carbon neutrality [39], the carbon neutrality capacity of the offshore fishing industry is calculated in Equation (1):

$$C_{net} = C_{em} - C_s \tag{1}$$

C_{net} represents the net carbon emission of offshore fishery, C_{em} represents the carbon emission of the offshore fishing industry and C_s represents the carbon sink of offshore fishing. When $C_{net} \leq 0$, it is completely carbon neutral, indicating that the carbon emission generated by offshore fishery can be completely offset by the capture carbon sink; when $C_{net} > 0$, it is partially carbon neutral. Net carbon emissions reflect the balance between carbon emissions and carbon sinks. When net carbon emissions are low, it indicates that the offshore fishing industry has a high carbon neutrality ability.

3.1.1. Estimation of Carbon Emissions from Marine Fisheries

Previous studies have shown that the fossil energy combustion of marine fishing vessels is an important source of carbon emissions from the marine fishing industry. Therefore, this study calculated the carbon emissions of offshore motorized fishing vessels as the carbon emissions of the offshore fishing industry. Fuel consumption can be obtained according to the power and fuel coefficient of marine fishing vessels in different operating modes, and the carbon emission can be calculated in combination with the carbon emission coefficient, as shown in Equation (2):

$$C_{em}^{T} = \left(\sum P_i \cdot \mu_i\right) \cdot \theta \cdot q \tag{2}$$

In Equation (2), P represents fishing vessel power in different operation modes, μ represents oil coefficient, θ represents carbon emission factor, q represents the average low calorific value of diesel oil and i represents operating modes of marine fishing vessels, including trawl, purse seine, gill net, open net, fishing tackle and others. As the power in different operation modes in the China Fishery Yearbook does not separate the power of offshore fishing vessels from that of pelagic fishing vessels, the carbon emission C_{em}^{T} calculated in Equation (2) is the total carbon emission of offshore fishing and pelagic fishing.

The carbon emission of the marine fishing industry is related to the fuel consumption of fishing vessels, and the fuel consumption is obtained according to the power of fishing vessels. Therefore, the carbon emission of offshore fishery is estimated according to the proportion of the power of offshore fishing motor vessels to the total power of marine fishing motor vessels, as shown in Equation (3):

$$C_{em} = C_{em}^{T} \cdot \frac{P^{*}}{P^{T}} \tag{3}$$

where C_{em} is the carbon emission of offshore fishery, P^{*} represents the power of offshore motorized fishing vessels and P^{T} represents the total power of marine motorized fishing vessels; that is, the sum of the power of offshore fishing and pelagic fishing motorized fishing vessels.

3.1.2. Estimation of Carbon Sinks from Marine Fisheries

Marine organisms sequestrate carbon in the form of biological pumps. Primary producers such as phytoplankton transform carbon in seawater from inorganic carbon to organic carbon through photosynthesis, and then transfer it from a lower nutrient level to a higher trophic level through the food chain [5]. The marine fishing industry removes part of the carbon from the water by fishing the catch to achieve "carbon transfer", which is the marine fishing carbon sink. Referring to Zhang et al. [25], the trophic level method was used to evaluate the carbon sink of offshore fishing; that is, according to the catch and the corresponding trophic level, the amount of the primary producer being consumed was derived based on the energy transfer process, and then the marine fishing carbon sink was estimated according to its carbon content. The specific process is as follows:

(1) Biomass of prey (B_1) with average trophic level between 1 and 2 was estimated by conversion of trophic level, see Equation (4).

$$B_1 = \frac{Y_0}{ECE_{(TL_0-k)}!} \tag{4}$$

where Y_0 means catch, TL_0 represents the trophic level of the catch and ECE represents the ecological conversion efficiency among the trophic levels. Because the trophic levels of catches are different, the transformation of trophic levels is different. k is a parameter related to the trophic level of catches. When the trophic level of catches is between 2 and 3, 3 and 4 and 4 and 5, k is 1, 2, 3, respectively. The ecological conversion efficiency ECE is determined by referring to the research of Tang et al. [40] (see Equation (5)).

$$ECE = -15.615 \cdot TL + 86.235 \tag{5}$$

(2) The biomass of preyed primary producers (B_0) is calculated. The proportion of primary producers with trophic level 1 and primary consumers with trophic level 2 among the ingested is first calculated (see Equation (6)):

$$1 \times \alpha + 2 \times (100\% - \alpha) = TL_0 - k \tag{6}$$

where α is the proportion of primary producers with trophic level 1.

The biomass B_0 of primary producers such as phytoplankton is then further estimated in Equation (7):

$$B_0 = B_1 \times \alpha + B_1 \times (100\% - \alpha)/ECE_{TL=1} \tag{7}$$

$ECE_{TL=1}$ represents the ecological conversion efficiency of primary producers such as phytoplankton consumed by primary consumers..

(3) Assuming that the carbon content of primary producers such as phytoplankton is 4.49% [41], the removed carbon sink is estimated to be the carbon sink of the marine fishing industry (C_s). See Equation (8):

$$C_s = B_0 \times 4.49\% \tag{8}$$

Offshore catches can be divided into fish, crustaceans, shellfish, algae, cephalopods and others. The total yield of fish, crustaceans and cephalopods accounted for an average of 92.45% of the total yield of offshore fishing products in 2010–2019, and the trophic level was high. Other marine catches have low yields and low or more difficult to determine trophic levels, so carbon transfer through the food chain/web of fish, crustaceans and cephalopods is used as a marine fishery carbon sink.

3.2. LMDI Decomposition Method

The Kaya identity [42] proposed by Yoichi Kaya reflects the impact of energy intensity, economic growth, population size and other factors on carbon dioxide emissions. The logarithmic mean division index (LMDI) decomposition method [43] decomposes multiple driving factors of carbon emissions based on Kaya identity to investigate the impact of various factors on carbon emissions. The LMDI decomposition method can eliminate the residual term, meet the requirements of reversible factors and has the advantage of unique results. Therefore, it is widely used in the analysis of carbon-related influencing factors in various fields. This study analyzed the driving factors of net carbon emissions from China's offshore fishing industry from 2010 to 2019 by using the additive form of the LMDI decomposition method.

Firstly, Equation (9) is used to express the net carbon emission of the offshore fishing industry:

$$C_{net} = \frac{C_{net}}{E} \cdot \frac{E}{Q} \cdot \frac{Q}{PE} \cdot PE = e \cdot f \cdot g \cdot PE \tag{9}$$

where E is the total energy consumption of the offshore fishing industry, Q is the catch output of the offshore fishing industry and PE is the number of employees of the offshore fishing industry. $e = C_{net}/E$ is net carbon coefficient, representing the net carbon emission per unit energy consumption; $f = E/Q$ is energy intensity, representing energy consumption per unit catch; $g = Q/PE$ is industrial development, representing per capita catch output, reflecting the output level of the offshore fishing industry and PE reflects the population size of the offshore fishery.

C^0_{net} and C^t_{net} refer to the net carbon emissions of offshore fishing in the base period and t period, respectively. According to the additive LMDI decomposition method, Equation (10) can be obtained:

$$\Delta C_{net} = C^t_{net} - C^0_{net} = \Delta C_e + \Delta C_f + \Delta C_g + \Delta C_{PE} \tag{10}$$

In Equation (10), net carbon emission changes are decomposed into four factors: net carbon coefficient effect (ΔC_e), energy intensity effect (ΔC_f), industrial development effect (ΔC_g) and population size effect (ΔC_{PE}). The contribution values of each factor are calculated as shown in Equation (11)

$$\begin{cases} \Delta C_e = L\left(C^t_{net}, C^0_{net}\right) ln\left(\frac{e^t}{e^0}\right) \\ \Delta C_f = L\left(C^t_{net}, C^0_{net}\right) ln\left(\frac{f^t}{f^0}\right) \\ \Delta C_g = L\left(C^t_{net}, C^0_{net}\right) ln\left(\frac{g^t}{g^0}\right) \\ \Delta C_{PE} = L\left(C^t_{net}, C^0_{net}\right) ln\left(\frac{PE^t}{PE^0}\right) \end{cases} \tag{11}$$

$L\left(C^t_{net}, C^0_{net}\right)$ is the logarithmic average function defined as follows (see Equation (12)):

$$L(x,y) = \begin{cases} \frac{x-y}{lnx-lny}, x \neq y \\ x, x = y \\ 0, x = y = 0 \end{cases} \tag{12}$$

3.3. Data Sources

In this work, the carbon neutrality level of the offshore fishing industry was studied by using the data of 11 coastal provinces in China (except Hong Kong, Macao and Taiwan) from 2010 to 2019, and the driving factors of net carbon emissions from offshore fishing industry were analyzed by using the LMDI decomposition model. The fuel coefficient of marine motor fishing boats in different operating modes refers to the Reference Standard for Calculating the Oil Price Subsidy of Domestic Motor Fishing Vessels. The carbon emission factor and the average low calorific value of diesel oil come from the IPCC Guidelines for National Greenhouse Gas Inventory 2006 and General Principles for Calculation of Comprehensive Energy Consumption, respectively. In the calculation of marine capture carbon sink, the trophic levels of fish mainly come from Fishbase and Sealifebase, and trophic levels of unclassified fish, crustaceans and cephalopods are represented by their respective average values. Other data come from China Fishery Yearbook and China Fishery Statistical Yearbook.

In addition, the “number of professionals in marine fishing” in the China Fishery Statistical Yearbook includes both the total number of professional practitioners in offshore fishing and those in pelagic fisheries, and it is not possible to directly obtain data on the number of professional practitioners in offshore fishing. The number of fishing boat personnel in actual production is directly related to the power of the fishing boat. Generally speaking, the higher the power of the fishing boat, the more operators are required. Therefore, the number of offshore fishing practitioners is estimated according to the ratio of the power of the offshore motorized fishing boat to the total power of the marine motorized fishing boat. The total energy consumption calculated based on the power also includes the energy consumption of the offshore fishing industry and the pelagic fisheries, and E is calculated based on the power ratio of the offshore motorized fishing vessel in the same way.

4. Results and Analysis

4.1. Carbon Neutrality in Offshore Fishing Industry

According to the assessment method of the carbon neutrality level of the marine fishing industry, the net carbon emissions of the marine fishing industry in the whole country and each coastal province were estimated, and the calculation results are shown in Table 1. It can be seen from Table 1 that the carbon emission of the offshore fishing industry in the whole country and each coastal province is higher than that of the marine fishing carbon sink. Therefore, China's offshore fishery is still partially carbon neutral.

Table 1. Net carbon emissions from China's offshore fishing industry in 2010–2019 (10^4 t).

Region	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
China	186.91	186.24	178.21	171.61	169.01	171.73	156.09	174.94	178.08	176.81
Tianjin	0.86	0.99	1.31	0.27	0.65	1.01	1.08	1.39	1.25	1.26
Hebei	7.94	7.91	7.05	7.96	8.89	8.65	7.43	7.15	7.45	7.99
Liaoning	21.59	20.59	19.11	15.27	13.48	16.85	12.50	22.67	25.76	24.54
Shanghai	1.61	1.68	1.64	1.28	1.49	1.49	0.72	0.45	1.37	0.82
Jiangsu	7.19	9.25	9.87	9.40	9.35	10.98	10.82	12.29	13.11	12.50
Zhejiang	50.28	48.44	49.35	44.62	43.54	39.13	34.98	31.22	34.76	34.87
Fujian	17.37	17.96	17.25	19.56	16.94	20.29	17.52	20.18	20.66	27.47
Shandong	8.93	10.67	9.23	9.19	7.47	10.80	9.03	13.44	7.13	3.91
Guangdong	42.07	41.35	40.31	40.06	39.30	36.96	35.80	33.52	32.60	31.79
Guangxi	16.43	14.81	12.16	12.86	12.55	11.50	12.51	12.48	13.46	13.59
Hainan	12.24	12.19	11.09	11.70	16.44	14.56	14.34	20.29	21.05	18.89

During the study period, the change of net carbon emissions from offshore fishing in China can be roughly divided into two stages: from 2010 to 2016, it showed a rapid downward trend, from 1,869,100 tons in 2010 to 1,560,900 tons in 2016, a decrease of 16.49%; from 2016 to 2019, it showed an upward trend, but the increment was lower. Therefore, the net carbon emissions of China's offshore fishing industry declined as a whole.

Specifically, the carbon emissions and carbon sinks of China's offshore fishing industry are shown in Figure 1. According to the total carbon emission and its year-on-year growth rate as shown in Figure 1, the carbon emission of China's offshore fishing industry fluctuated from 2010 to 2015, with the highest growth rate of 1.93% in 2015. However, the year-on-year growth rate of carbon emission after 2016 was always lower than 0, showing a continuous downward trend. The decline in 2017 was the largest, with the year-on-year growth rate of −5.43%. The offshore fishing carbon sink showed a general trend of increasing first and then decreasing, rising from 2,798,200 tons in 2010 to the highest value of 3,005,400 tons in 2016and declining rapidly after 2016. In 2019, the offshore fishing carbon sink was only 2,317,500 tons, decreasing by 22.89% compared with 2016.

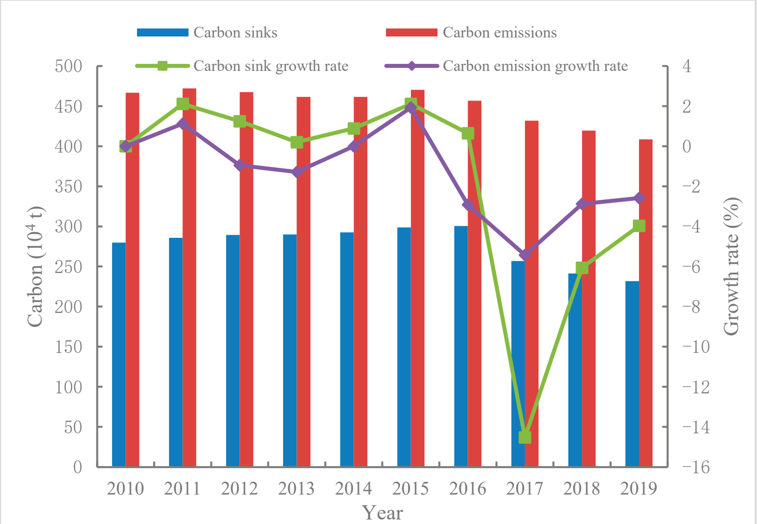


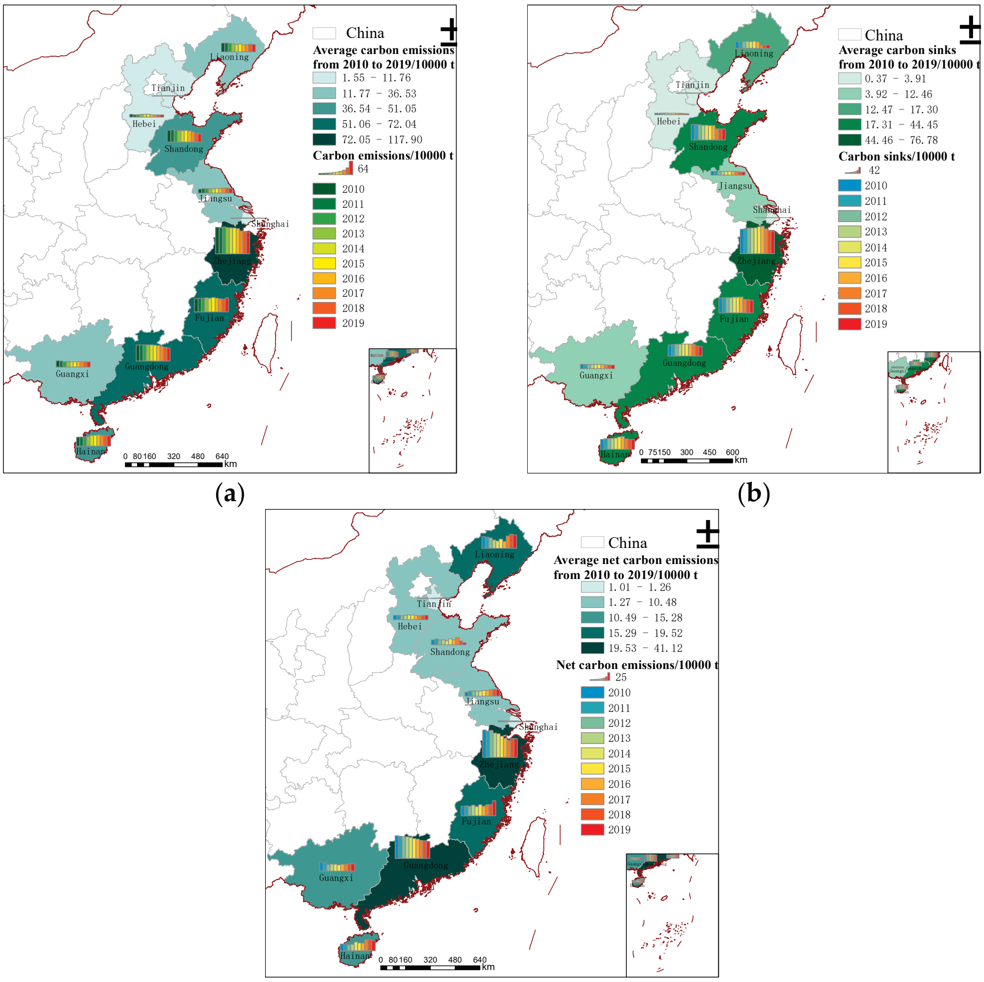
Figure 1. Carbon change in China's offshore fishing industry from 2010 to 2019.

According to the provincial results of net carbon emissions from offshore fishing shown in Table 1, there are large regional differences in net carbon emissions from offshore fishing. Zhejiang has the highest net carbon emission from offshore fishing, with an average net carbon emission of 411,200 tons during the study period, ranking first among coastal provinces, followed by Guangdong province, the net carbon emission of which even exceeded Zhejiang province in 2016 and 2017. However, the net carbon emission of both provinces showed a general downward trend, showing a good trend of low-carbon development. Tianjin and Shanghai had relatively low net carbon emissions. The average net carbon emissions of Tianjin's offshore fishing industry from 2010 to 2019 were only 10,100 tons.

Figure 2 shows the average levels and time-series changes of carbon emissions, carbon sinks and net carbon emissions from the offshore fishing industry in China's coastal provinces from 2010 to 2019. It can be seen from Figure 2 that the offshore fishing industry in Zhejiang belongs to the type of high carbon emission and high carbon sink. Zhejiang has a large-scale marine fishing industry. In 2019, the power of its offshore fishing boats was about 2,774,700 kW, accounting for 25.93% of the total power of motorized fishing boats for offshore fishing in China, so carbon emissions were high. Zhejiang has the largest fishing ground in China (Zhoushan fishing ground). It is rich in fishery resources and is the main producing area of marine aquatic products. In 2019, the output of offshore fishing accounted for 27.23% of the total output of offshore fishing in China. Therefore, the carbon sink of offshore fishing is also high. In general, the net carbon emissions of offshore fisheries in Zhejiang are high, and the process of the carbon neutrality of the marine capture fisheries has a long way to go. The offshore fishing industry in Tianjin and Shanghai is of a low-carbon emission and low-carbon sink type, which may be due to the small scale of the offshore fishing industry.

Carbon emissions from offshore fishing in most provinces showed a downward trend. Among them, Zhejiang, Guangdong and Shandong have large carbon emission bases and obvious emission reduction effects. During the study period, the carbon sink change of the offshore fishing industry in most provinces was consistent with that of the whole country, showing a trend of first rising and then falling. The reduction in marine fishing carbon sink may be caused by the decline of marine fishing output. The Thirteenth Five-Year Plan for National Fishery Development issued by the Ministry of Agriculture in 2016 emphasized that the domestic fishing intensity should be gradually reduced, the domestic fishing output would achieve "negative growth" and the domestic marine fishing output should be controlled within 10 million tons by 2020. In 2017, the pilot work of quota fishing was launched. The implementation of a series of measures to control offshore fishing led to a significant decline in offshore fishing output in 2016, and the carbon sink of offshore fishing decreased in 2016.

It is worth noting that Fujian's offshore fishing output was always lower than that of Shandong from 2010 to 2019, but its offshore fishing carbon sink began to be higher than that of Shandong from 2013, which may be caused by the low average trophic level of Shandong's marine fishing catch. The carbon sink of marine fishing is affected by the fishing output and the trophic level of the catch. Although increasing the fishing output can increase the carbon sink, overfishing may lead to the destruction of the marine ecosystem and the decline of the trophic level, which is also not conducive to the sustainable development of the carbon sink function of marine fishing. Therefore, it is necessary to develop resource conservation fisheries and realize the sustainable development of marine fisheries.



(**a**) (**b**)

(**c**)

Figure 2. Temporal and spatial distribution of carbon in offshore fishing in China's coastal provinces from 2010 to 2019. (**a**) Carbon emissions of offshore fishing; (**b**) Carbon sinks of offshore fishing; (**c**) Net carbon emissions of offshore fishing.

4.2. Empirical Analysis of Driving Factor Decomposition

Identifying the driving factors of net carbon emissions from marine fisheries can help us understand the real reasons for the change in the carbon neutrality capacity of marine fisheries and formulate measures to improve the carbon neutrality level of marine fisheries. In this study, the contribution of the net carbon coefficient, energy intensity, industrial development and population size to the change of net carbon emission of offshore fishery in China and coastal provinces was calculated with the LMDI decomposition model. The annual effects of each driving factor of net carbon emissions from China's offshore fishing industry during 2010–2019 are shown in Table 2, and the annual cumulative effects are shown in Figure 3. From the cumulative effect of driving factors, industrial development is the main positive driving factor of net carbon emissions from China's offshore fishing industry, while population size is the main restraining factor. The contribution value of the net carbon coefficient and energy intensity is also positive, which also drives the net carbon emissions from China's offshore fishing industry to a certain extent.

Table 2. Decomposition results of net carbon emissions from China's offshore fishing industry from 2010 to 2019 (10^4 t).

Year	ΔC_e	ΔC_f	ΔC_g	ΔC_{PE}	Total Effect
2011	−2.751	−3.771	12.662	−6.811	−0.670
2012	−6.303	−5.402	2.638	1.029	−8.038
2013	−4.330	−1.872	0.171	−0.558	−6.590
2014	−2.592	−2.214	12.168	−9.966	−2.604
2015	−0.534	−1.207	11.291	−6.835	2.716
2016	−10.790	−6.518	9.087	−7.416	−15.638
2017	28.082	20.091	−23.923	−5.397	18.853
2018	8.294	5.968	−2.452	−8.674	3.136
2019	3.383	3.045	1.942	−9.634	−1.265
Average effect	1.384	0.902	2.620	−6.029	−1.122
2010–2019	12.458	8.120	23.583	−54.262	−10.100

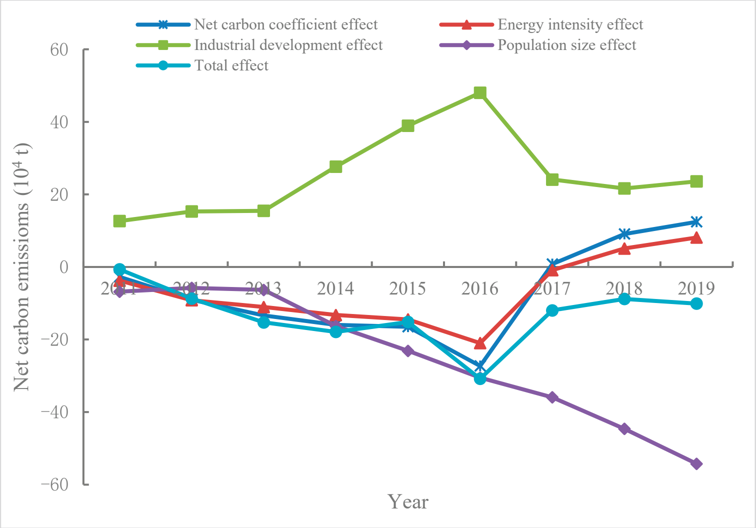


Figure 3. Cumulative effect of driving factors of net carbon emissions from China's offshore fishing industry from 2010 to 2019.

As shown in Figure 3, industrial development has always been the main positive driving factor for the net carbon emissions of China's offshore fishing industry. Before 2016, the cumulative effect of industrial development expanded year by year and was the only positive driving factor. After 2016, the driving effect of industrial development weakened, but the cumulative effect of the net carbon coefficient and energy intensity began to turn positive, which together caused the net carbon emissions to increase. From 2010 to 2019, the cumulative effect of population size has been expanding year by year, which has continuously inhibited the net carbon emissions of the marine fishing industry. Overall, the driving direction and changing trend of the net carbon coefficient and energy intensity are the same.

(1) Net carbon coefficient effect. From 2010 to 2019, the cumulative contribution of the net carbon coefficient factor to the carbon emission of China's offshore fishing industry was 124,580 tons, and the annual average contribution value was 13,840 tons. In general, the change of the net carbon coefficient promoted the net carbon emission of the offshore fishing industry. However, from the year-on-year effect of the net carbon coefficient shown in Table 2, the contribution value of the net carbon coefficient factor from 2010 to 2016 was negative, exerting a restraining effect on the net carbon emission. After 2017, the positive driving effect of the net carbon coefficient weakened, and the overall trend was good. The net carbon coefficient reflects the net carbon emission per unit of energy consumption. Although the carbon emission coefficient of energy consumption in this paper is a fixed

value, and the net carbon coefficient is mainly affected by carbon sink, increasing the proportion of clean energy and fundamentally reducing the net carbon emission coefficient of energy are effective measures to improve the carbon neutrality capacity of the marine fishing industry.

(2) Energy intensity effect. From 2010 to 2019, the cumulative contribution value of energy intensity was 81,200 tons, and the annual average effect was 9020 tons, which played a certain role in promoting the net carbon emissions of China's offshore fishing industry. As shown in Figure 3, the cumulative effect of energy intensity is positive, which is mainly affected by the increase in marine fishing energy intensity in 2017–2019. Energy intensity, that is, the energy consumption per unit output, reflects the energy dependence of the marine fishing process. Although the energy consumption is reduced, the catch output is significantly reduced, resulting in the energy intensity effect changing from negative to positive. This is influenced to a certain extent by the fishing quota system, but it also indicates that energy efficiency should continue to be improved in the future, and unnecessary energy consumption should be reduced through measures such as strengthening marine fishery resource surveys. At the same time, the marine fishing structure should be optimized and the proportion of high-energy-consuming fishing methods such as trawling should be reduced.

(3) Industrial development effect. From 2010 to 2019, the cumulative increment of carbon emissions generated by industrial development was 235,830 tons, with an average contribution value of 26,200 tons. Industrial development is the main driving factor behind the net carbon emissions of China's offshore fishing industry. This shows that industrial development mainly depends on general technological progress; that is, improving production efficiency and promoting the increase in fishery output through the mechanization of fishing operations and increasing the use of energy-consuming fishing machines. On the other hand, the effect value of industrial development began to appear negative, which also showed that the development of the marine fishing industry was gradually realizing carbon decoupling, and the emission reduction effect was significant.

(4) Population size effect. From 2010 to 2019, the cumulative effect of population size on the net carbon emissions of China's offshore fishing industry was −542,620 tons, with an average effect of −60,290 tons, which is the main driving factor to improve the carbon neutrality level of the offshore fishing industry. As shown in Table 2 and Figure 3, except for 2012, the annual effect of population size is negative, indicating that the change of population size has a continuous inhibitory effect on net carbon emissions. The carbon emission reduction effect of the population size factor is mainly caused by the shrinking population size of the marine fishing industry. Compared with 2010, the estimated number of offshore fishing professionals in 2019 decreased by about 26.95%. The reduction in population size reduces the demand for marine fishing, and reduces some high-energy marine fishing production activities, exerting a restraining effect on net carbon emissions. The decrease in the number of marine fishing professionals reflects the effectiveness of the policy of changing industries. In the future, the support of the policy should be strengthened continuously, so as to arouse the enthusiasm of the fishermen to reduce the number of boats and to realize the high-quality development of marine fishery.

It should be noted from the statistical data that the number of professional practitioners of marine fishing is declining steadily, which has a restraining effect on the carbon emissions of marine fishing. In fact, marine capture fishery practitioners have changed from traditional fishermen who lived on the sea as a single subject to a pattern of coexistence of traditional fishermen specializing in marine fishing, fishermen and farmers who engage in part-time and temporary fishing, fishery cooperative organizations and fishery enterprises. The scale of the fishermen increased [44], which may have a certain impact on the LMDI decomposition results of the driving factors of net carbon emissions in the offshore fishing industry.

The cumulative contribution of driving factors to the net carbon emissions of the offshore fishing industry in 11 coastal provinces in China from 2010 to 2019 is shown in

Table 3, and the year-by-year effects of the previous year as the base period are shown in Figure 4. From the cumulative effect values shown in Table 3, it can be seen that except for Tianjin and Hainan, the population size factor is a negative driving effect. For Hebei, Liaoning, Jiangsu, Fujian and Hainan, the driving direction of the net carbon coefficient and energy intensity is the same, which drives the net carbon emissions of the offshore fishing industry. In terms of industrial development, the effect values of Tianjin, Hebei, Liaoning, Guangxi and Hainan are negative, which inhibits the net carbon emissions.

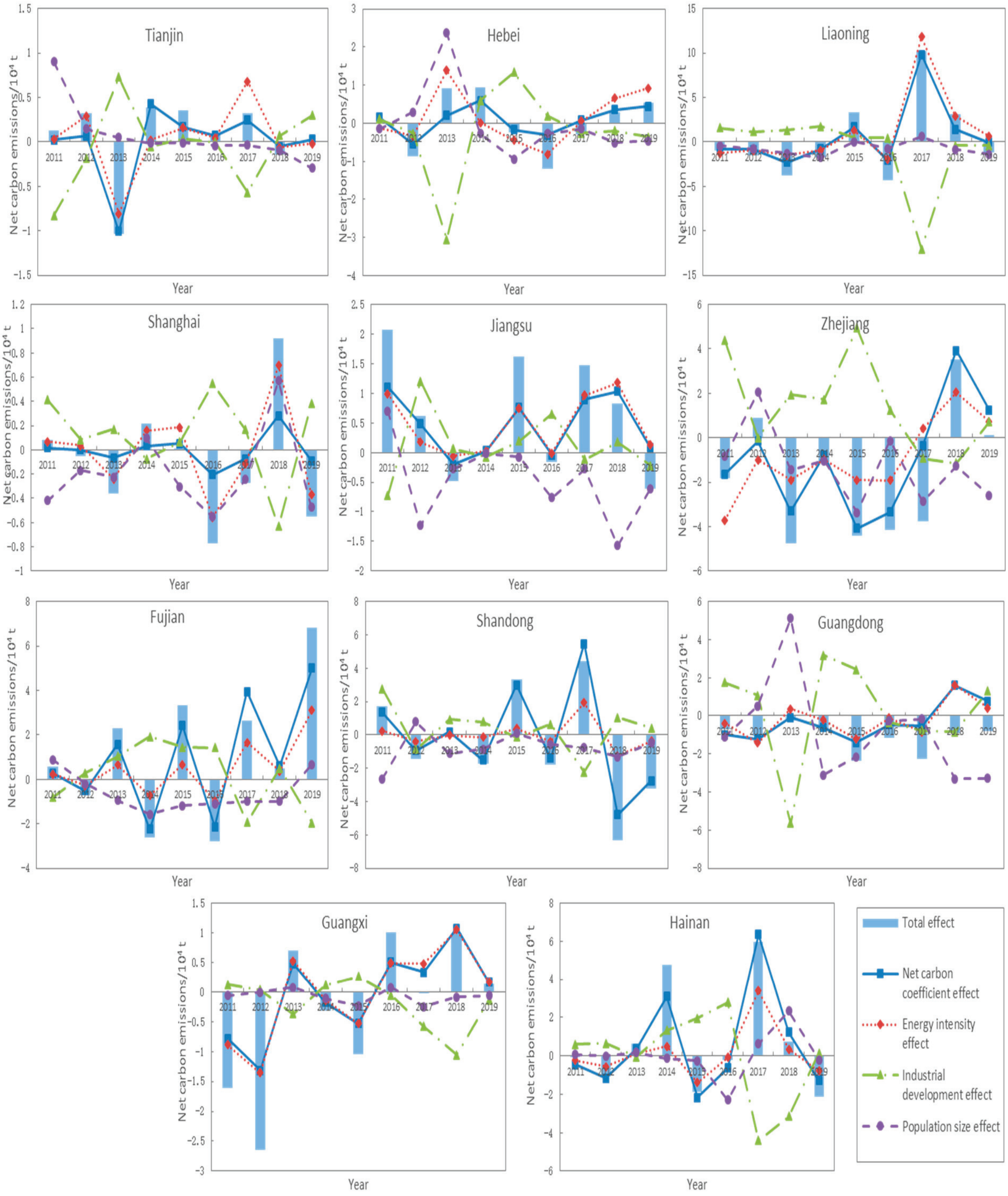


Figure 4. Decomposition results of net carbon emissions from offshore fishing in China's coastal provinces from 2010 to 2019.

Table 3. Decomposition results of net carbon emissions from offshore fishing in China's coastal provinces from 2010 to 2019 (10^4 tons).

Region	ΔC_e	ΔC_f	ΔC_g	ΔC_{PE}	Total Effect
Tianjin	−0.033	0.342	−0.508	0.599	0.400
Hebei	0.774	1.299	−1.921	−0.106	0.046
Liaoning	6.029	10.030	−6.385	−6.720	2.954
Shanghai	−0.052	−0.134	1.120	−1.720	−0.786
Jiangsu	4.136	4.157	1.141	−4.123	5.311
Zhejiang	−8.498	−8.235	12.840	−11.516	−15.409
Fujian	8.921	4.704	1.925	−5.449	10.102
Shandong	−1.421	−0.031	3.297	−6.863	−5.018
Guangdong	−2.910	−1.820	2.154	−7.703	−10.278
Guangxi	−0.261	−0.212	−1.677	−0.684	−2.834
Hainan	5.280	1.303	−0.202	0.273	6.654

The province with the highest cumulative effect of net carbon coefficient from 2010 to 2019 is Fujian, which is the main factor influencing the change of net carbon emissions in Fujian, with a contribution rate of 42.48%. The net carbon coefficient effect in Fujian shown in Figure 4 shows a fluctuating upward trend, especially since 2017, and the cumulative contribution value is 95,350 tons. In response to the strategy of the negative growth of marine fishing output, Fujian's fishing output decreased from 2,038,600 tons in 2016 to 1,611,600 tons. In the case of small changes in fishing energy consumption, the marine fishing carbon sink is reduced, resulting in an increase in the net carbon coefficient, which drives the net carbon emissions of marine fishing. Energy intensity is the main factor affecting the net carbon emissions of Liaoning's offshore fishing industry. From 2016 to 2017, the energy consumption of offshore fishing in Liaoning increased by 1.95%, while the fishing output decreased by 48.96%, resulting in an increase in energy consumption per unit of output from 0.35 to 0.69. The increasing effect is significant. Industrial development is a positive driver of net carbon emissions from the offshore fishing industry in Shanghai, Jiangsu, Zhejiang, Fujian, Shandong and Guangdong, indicating that the increase in per capita fishing production in these regions is still highly dependent on energy. In the future, it is necessary to strengthen the research and promotion of energy-saving fishing machines and low-carbon fishing technologies. The population size change in Tianjin has the highest positive promotion effect on the net carbon emissions of the offshore fishing industry, which may be due to the small scale of its early marine fishing industry. In general, the population scale effect of most provinces is exerting a continuous inhibitory effect, and the overall trend is good.

The change of the effect value of the driving factors shows strong policy relevance. Taking Shandong Province as an example, due to the negative growth policy of marine fishing output and the management of quota fishing, its marine fishing output in 2017 decreased by 23.67% year-on-year, and the change of output is much higher than that in other years. The change of marine fishing output affects the net carbon emission, the net carbon coefficient and energy intensity change from negative to positive and the effect of industrial development change from positive to negative, and the change of effect value was also higher than that in other years. On the other hand, the impact of this policy is not sustainable. It only has a great impact on the effect value in the early stage of the policy. It may be that at the beginning of the policy, fishery management is relatively strict. When the target is expected to be achieved, the corresponding fishery management will be relaxed, which will affect the sustainable development of the policy effect. In general, the improvement of the carbon neutrality level in marine fisheries not only depends on the introduction of policies but is also affected by the degree of policy implementation.

5. Discussion

The carbon emissions of China's offshore fishing industry declined rapidly after entering the 13th Five Year Plan, which is similar to the research conclusion of Li et al. [38]. This is because, since the 13th Five Year Plan, China's fishery has advocated ecological priority and green development, and the number of marine fishing motor vessels has rapidly decreased, which has contributed to the reduction in carbon emissions, indicating that this policy has an important guiding significance for the low-carbon development of China's marine fisheries.

The use of the trophic level method to assess the carbon sink of offshore capture fisheries in this study is relatively rare in the study of the carbon sink of fisheries. Compared with the carbon removal results (1,430,000–1,570,000 t/year) calculated by Gao et al. [22] based on the C sequestration rate of the catch, the carbon sink obtained from the trophic level method is higher. A possible reason is that the average transfer efficiency between different trophic levels, the trophic levels of different species of organisms, the average value of phytoplankton carbon content and the carbon content between different species of organisms of different fishing species all influence the results.

From the LMDI decomposition results, industrial development promoted the increase in net carbon emissions from China's offshore fishing industry, which is similar to the findings of Li et al. [31] and Shao et al. [30]. Industrial development has contributed to an increase in the demand for marine capture products and an increase in the use of large machinery and equipment for fishing activities, leading to an increase in the potential demand for energy consumption and an expansion of the carbon emission base. The population size promotes carbon emission reduction in the offshore fishing industry, which is consistent with the findings of Li et al. [31] and opposite to those of Zhu et al. [37]. This may be due to the shrinkage of the employed population in the offshore fishing industry in this study, while the population size increased in the study of Zhu et al. [37]. Energy intensity played an inhibitory role during 2010–2016, which is similar to the conclusions of Shao et al. [30] and Wang et al. [35], but it started to have a positive effect in 2017. The difference in results may be due to the significant reduction in marine fishing yield in the late period of the study and the difference in the choice of indicators. The energy intensity index in this paper refers to the energy consumption per unit of production, not the energy consumption per unit of output.

The net carbon emission assessment results show that the carbon emission of the offshore fishing industry in China is still relatively high. Ecological priorities will help reduce carbon emissions from offshore fishing. The offshore fishing industry has great potential of carbon sink, so more attention should be paid to the carbon sink function of capture fisheries. With the decline of marine fishing intensity, the catch decreases and the marine fishing carbon sink also decreases. Therefore, the marine fishing yield is still an important factor affecting the marine fishing carbon sink. However, it should be noted that overfishing will lead to the decline of marine biological resources and the decrease in the average trophic level of catch species, which is not conducive to long-term carbon sink function. Therefore, resource-conserving fisheries should be developed from a long-term perspective. In addition, different research methods differ in the estimation of carbon sinks, so it is necessary to strengthen the research on the calculation method of carbon sinks and form a scientific evaluation system of fishery carbon sinks.

From the decomposition results, the reduction in the net carbon emissions of the offshore fishing industry depends on the control of energy intensity, the reduction in population size and the decoupling of industrial development. Therefore, in order to achieve low-carbon development in the offshore fishing industry, it is necessary to continue to adhere to the system of vessel reduction and production conversion while guiding the progress of low-carbon technology in the offshore fishing industry to achieve carbon decoupling.

6. Conclusions and Recommendations

This study evaluated the carbon neutral status of China's offshore fishing industry from 2010 to 2019 and analyzed the dynamic trends of carbon emissions, carbon sinks and net carbon emissions. The LMDI decomposition method was used to decompose the driving effects of each driving factor of net carbon emissions. The main conclusions are as follows:

(1) China's offshore fishing industry is still in a partially carbon neutral state, and the overall carbon neutral capacity is improved. The change of net carbon emissions can be divided into two stages: 2010–2016 is a rapid decline stage, and 2016–2019 is an upward stage. The carbon emissions from offshore fishing fluctuated from 2010 to 2015, and decreased rapidly from 2015 to 2019. The offshore fishing carbon sink showed a trend of rising first and then decreasing, and reached the maximum value in 2016.

(2) The offshore fishing industry in coastal provinces is also in a state of partial carbon neutrality. The trends of carbon emissions, carbon sinks and net carbon emissions in most provinces are consistent with those in China, but there are large differences between regions. As a major marine fishing province, Zhejiang's carbon emissions, carbon sinks and net carbon emissions are much higher than other provinces, while Tianjin and Shanghai are far lower than other provinces due to their small marine fishing scale.

(3) For the whole country, the net carbon coefficient, energy intensity and industrial development have positive cumulative effects on net carbon emissions. Industrial development is the main factor driving the increase in net carbon emissions from offshore fishing, while population size is the main factor restraining the growth of carbon emissions.

(4) Population size is an important inhibitory factor for the net carbon emissions of the offshore fishing industry in most coastal provinces, while the net carbon coefficient, energy intensity and industrial development factors have different driving directions for different provinces.

Based on the above research, the following suggestions are put forward for the low-carbon development of the marine fishing industry:

The marine fishing industry has great potential of carbon sink, so more attention should be paid to its ecological function. In order to realize the long-term carbon sink function of the offshore fishing industry, the principle of sustainable development should be adhered to. The restoration of marine fishery resources and the ecological environment can be promoted by controlling the intensity of marine fishing, establishing artificial fishing reefs and developing marine pastures.

According to the LMDI decomposition results, the following measures can be taken to improve the carbon neutrality of the marine fishing industry. To reduce the carbon emission coefficient of energy through the low carbonization of the energy structure, the structure of marine fishing should be optimized to reduce energy intensity using information and intelligent means to improve energy efficiency. It is necessary to reasonably control the size of the marine fishing population and strengthen the education and training of marine fishing personnel. In addition, it is important to strengthen policy guidance, encourage the research and development of energy-saving and environmental protection technologies and guide the green development of industries.

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Article

Integration of Marine and Terrestrial Ecological Economies in the Cities of the Bohai Rim, China, Based on the Concept of Viscosity

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Abstract: The integration of sea and land ecological economies is crucial for the development of a high-quality sea–land economy. This study explores and proposes the concept of a sea–land-integrated ecological economy. By constructing the evaluation index system for developing a sea–land-integrated ecological economy, the development level, evolution process, and development trend prediction of a sea–land-integrated ecological economy were evaluated and analysed in cities around the Bohai Sea from 2009 to 2019 using methods such as a model for assessing the development level, a spatio-temporal autocorrelation model, and an exploratory spatio-temporal data analysis model. The results of the study show that (1) the development level of the ecological economy of the cities of Bohai Rim's sea–land integration generally had an upward trend; however, the magnitude significantly varied between cities; (2) the spatio-temporal autocorrelation pattern formed three major agglomerations with Dalian in the north, Yantai and Qingdao in the south, and Tianjin and Tangshan in the centre as the core cities and contained low agglomerations and scattered L–H spatio-temporal heterogeneous units; and (3) the integration prediction curve for 2020–2029 indicates that the level value for integration of most cities will improve over time.

Keywords: marine and terrestrial integration economy; viscosity thinking; spatio-temporal autocorrelation model; ESTDA; spatio-temporal prediction model; Bohai Sea Rim city

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1. Introduction

The sea and land are interdependent and interrelated. China has both land and sea, and the implementation of a comprehensive land and marine strategy is conducive to the coordinated development of marine and land-based economies. However, the traditional 'land-based' development concept has resulted in the double-track development of land-based and marine economies, and the ocean requires high economic and technological investment. This has led to a lag in oceanic development, ensuing contradictions between the land, sea, and air, as well as competition for resources. Thus, the land–sea economic differentiation contradiction is becoming increasingly evident. Therefore, promoting the marine economy is particularly crucial in driving the land-based economy, leading to the formation of a new pattern of quality development of sea and land integration [1–3]. At present, China is in a critical period of strategic adjustment of its economic structure and rapid development of the marine economy. Therefore, high-quality, coordinated, and sustainable development of the regional marine and land economy should be promoted by investigating a new type of marine and land integrated economy that adapts to contemporary development scenarios. Through the empirical measurement of the integration between marine and terrestrial ecological economy in the cities of the Bohai Rim, the characteristics and laws of this model are put forward to guide the coordinated and high-quality development of sea and land economy.

The integrated development of marine- and land-based economies is a decision-making tool for addressing the relationship between the economies. Chinese scholars have proposed the concept of land and marine coordination [4,5], and their research primarily focuses on the impact of the marine economy on the economic development of coastal areas and quantitative analysis of the marine- and land-based economies [6–9]. International scholars have focused more on the integrated management of coastal zones and the development of the marine economy at a regional or national scale [10–13]. The inevitable integrated development of marine- and land-based economies is attributed to the following facts: (1) the integration of sea and land and practical technological progress are external environmental factors; and (2) the fundamental connection between sea and land industries is the internal driving force, and industrial integration is an economic development trend that is highly significant for industrial expansion, the optimisation of industrial structure, and the enhancement of industrial competitiveness [14]. Current research on marine- and land-based economies mostly focuses on the qualitative and quantitative analyses of the correlation and coordination of indicators or industrial data under the concepts of sea–land interaction and integration, particularly the synergistic development of sea–land industries, coordinated evaluation of the sea–land economy, and measurement of sea–land integration levels [15–17]. However, detailed mechanisms and models for the integrated development of marine- and land-based economies are lacking. A multidisciplinary approach, with cross-regional empirical research at the municipal level, was adopted for this research, particularly from the output characteristics of marine- and land-based economies. The research on a sea–land-integrated economy is scattered and one-sided, lacking a certain degree of systematisation. The research primarily focuses on the qualitative analysis of the realisation path of sea–land integration and the integrated development of a certain aspect of simplification, as well as pure technical integration research [18–21]. The mutual influence and interaction between the marine and land economic systems were considered.

The Bohai Sea region is one of the three major maritime economic regions in China (Figure 1). Owing to its advantageous geographical location, rich and diversified resources, and progressive industry and technology, it has become the backbone of China's maritime economic development. Before the background of accelerating the high-quality development of China's marine economy, the evaluation of the sea–land integration ecological economy in cities around the Bohai Sea has important theoretical value and practical significance for accurately understanding the current scenario of the sea–land economic development of coastal cities and formulating measures that conform to the differences between regions. From a systems perspective, the integration of the marine and terrestrial ecological economies is an emerging system of continuous change formed by interconnection, intersection, penetration, competition, and collaboration among several sub-system components within the sea–land interface and its complex system in the spatio-temporal dimensions [22,23]. Considering its complexity, the sea–land issue should be comprehensively analysed and studied. Based on previous study results, this study used the framework of system theory to introduce the viscosity theory as a guide for the in-depth analysis of a mechanism and model for the integration of sea and land ecological economies. This was combined with a structural chart of the marine ecological economic system, and an evaluation index system was constructed for integrating marine and land ecological economies in cities around the Bohai Sea [24,25].

However, because of the limited research regarding scale and samples, research on the integration of marine and land economies is not comprehensive. In this study, 17 prefecture-level cities in the Bohai Rim were selected as the research areas, and the optimal entropy value and polygon quorum were used to measure the integration capacity of the urban sea–land system from 2009 to 2019. The spatial and temporal differentiation characteristics and dynamic change trends of the sea–land integration eco-economic level of cities in the Bohai Rim were explored. To address the spatio-temporal limitations, GeoDa and GIS software combined with spatio-temporal autocorrelation analysis (spatio-temporal Moran's I), an exploratory spatio-temporal data analysis (ESTDA) model, and spatio-temporal prediction integrated models were applied to analyse the spatio-temporal correlation of the sea–land integration eco-economic level of cities in the Bohai Rim. This study summarises the inner mechanism and evolutionary pattern of the sea–land integration ecological economy and explores the level and agglomeration characteristics in cities around the Bohai Sea, which is conducive to the high-quality growth of China's sea–land economy under the new scenario.

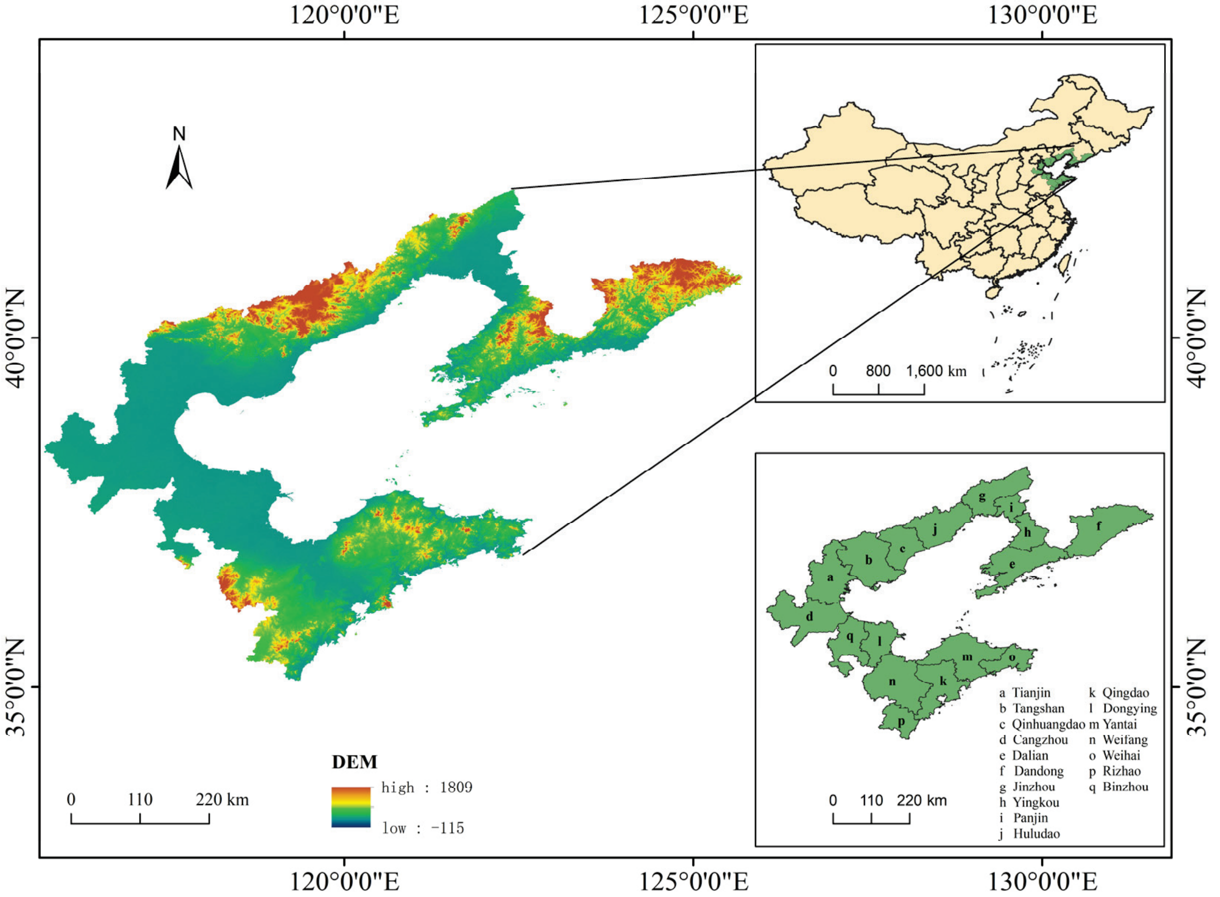

Figure 1. Location of the study area and the Circum-Bohai Sea, China. Source: geospatial data cloud.

2. Materials and Methods

2.1. Data Sources

The data sources used in this study include the 2010–2020 editions of the China Marine Statistical Yearbook, China City Statistical Yearbook, Shandong Statistical Yearbook, Liaoning Statistical Yearbook, Hebei Economic Yearbook, Tianjin Statistical Yearbook, Bulletin on Environmental Quality of China's coastal waters, and the statistical bulletins of the relevant national departments.

2.2. Research Methodology

The extreme difference method was used to normalise the raw data and eliminate the effects of dimensional differences on the results of this study. The marine- and land-based economies are open, large-scale systems with numerous components that both influence and restrict each other. Overall, they have the general characteristics of a complex system: open, dynamic, real-time, and spatial. The basic condition for the benign operation of a complex system is the coordinated development of each component [26].

2.2.1. Entropy Method

The entropy method was employed to calculate the time weights [27].

$$h_{ij} = -k\sum_{i=1}^{n} p_{ij} ln\left(p_{ij}\right) \tag{1}$$

$$e_j = 1 - h_{ij} \tag{2}$$

$$w_j = \frac{e_j}{\sum_{j=i}^{n} e_j} \tag{3}$$

where h_{ij} is the proportion of the index value of the i-th year under the j-th index of a prefecture-level city to the index value of all years, p_{ij} is the entropy value of the j-th index of a prefecture-level city, k is a constant, n is the number of schemes, e_j is the difference coefficient of the j-th index of a prefecture-level city, and w_j is the weight of index j of a prefecture-level city.

2.2.2. Model for Assessing the Development Level

The sequential arrangement of the polygon area considers a fixed point as the common point of multiple line segments extending outward to form a polygon, the multiple line segments of the common point represent specific terms, and the length of the line segments is the corresponding index value. The area of each triangle formed by the adjacent line segments of the common point in the sequential arrangement was calculated to obtain the polygon area, and the polygon area was regarded as the value of the comprehensive index. Furthermore, *O* is the origin, and *OI*, *OC*, *OE*, and *OU* represent the integration economy development foundation, integration economy resource development, integration economy industry linkage, and integration economy result creation, respectively. The area of this quadrilateral is regarded as the level of sea–land integration ecological economy development [28];

$$\eta = \frac{1}{2} sin\ \alpha (OI \times OC + OC \times OE + OE \times OU + OU \times OI) \tag{4}$$

$$\alpha = \frac{360^\circ}{4}$$

where η is the level value of the ecological economy of marine and terrestrial integration.

2.2.3. Spatio-Temporal Autocorrelation Model

Spatial autocorrelation analysis can only explore the aggregation of variables in a region at a given moment; thus, Moran's I can only be applied to the spatial dimension but cannot determine spatio-temporal autocorrelation properties in the time–space dimension. Wartenberg (1985) proposed a spatio-temporal autocorrelation structure for analysing variables using spatio-temporal Moran's I; by introducing the time dimension, the global and local spatio-temporal Moran's I extends and improves Moran's I [29]. Spatio-temporal autocorrelation analysis commonly uses a spatio-temporal weight matrix to determine the spatio-temporal proximity between objects and a spatio-temporal lag vector to determine the spatio-temporal neighbourhood state of each unit. Spatio-temporal Moran's I can effectively calculate the spatio-temporal correlation pattern between the original variable x at moment t-k and the spatial lag at moment t, while quantifying the effect of the change in variable x in region i at moment t-k on the impact of variable x around region i at moment t.

2.2.4. Global Spatio-Temporal Autocorrelation Formula

Global spatio-temporal autocorrelation formula

$$STI = \frac{\sum_{i=1}^{N}\sum_{j=1}^{N} W_{t-k,t}W_{ij}\left(X_{i,t-k} - \overline{X_{t-k}}\right)\left(X_{j,t} - \overline{X_t}\right)}{\sqrt{\sum_{i=1}^{N}\left(X_{i,t-k} - \overline{X_{t-k}}\right)^2} \times \sqrt{\sum_{i=1}^{N}\left(X_{i,t} - \overline{X_t}\right)^2}} \tag{5}$$

where N is the number of study areas; $W_{t-k,t}$ is the time weight from moment $t-k$ to moment t, usually set to 1; and W_{ij} represents the elements of the spatio-temporal weight matrix W. Owing to the time-invariant nature of the polygon region adjacencies, the spatial weight matrix can be used directly. $X_{i,t}$ and $X_{j,t}$ are the values of observations in cells i and j at time t; $X_{i,t-k}$ is the same observation in cell i at moment $t-k$; and $\overline{X_{t-k}}$ and $\overline{X_t}$ are the average values of the observed quantities at $t-k$ and moment t, respectively.

Local spatio-temporal autocorrelation formula

$$PSTI = \frac{NW_{t-k,t}\left(X_{i,t-k} - \overline{X_{t-k}}\right)\sum_{j=1}^{N} W_{ij}\left(X_{j,t} - \overline{X_t}\right)}{\sqrt{\sum_{i=1}^{N}\left(X_{i,t-k} - \overline{X_{t-k}}\right)^2} \times \sqrt{\sum_{i=1}^{N}\left(X_{i,t} - \overline{X_t}\right)^2}} \tag{6}$$

The local spatio-temporal Moran's I indicates the degree of correlation between the fusion value of the local area at time *t-k* and the fusion value of the surrounding area at time *t*. The variables in Equation (5) correspond to the global Moran's I [30,31].

2.2.5. Exploratory Spatio-Temporal Data Analysis Model (ESTDA)

The local indicator of spatial association (LISA) time path is based on the temporal migration of LISA coordinates in a Moran scatter plot. It incorporates the time dimension into the traditional static LISA, making it a dynamic continuous representation and a continuous representation of the LISA spatial Markov transfer matrix. It is typically used to reflect the local spatial and temporal synergistic changes in geographical elements, and reveal the extent and direction of spatial and temporal interactions of regional geographical elements (competing dynamics) and the extent of spatial and temporal dependence effects on the evolution of regional systems.

$$N_i = \frac{n \times \sum_{t=1}^{T-1} d(L_{i,t}, L_{i,t+1})}{\sum_{i=1}^{n}\sum_{t=1}^{T-1} d(L_{i,t}, L_{i,t+1})}, D_i = \frac{\sum_{t=1}^{T-1} d(L_{i,t}, L_{i,t+1})}{d(L_{i,t}, L_{i,T})} \tag{7}$$

where n is the number of cells, T is the annual interval, $L_{i,t}$ is the LISA coordinates of city i in year $t(y_{i,t}, yL_{i,t})$, $d(L_{i,t}, L_{i,t+1})$ is the distance that city i moved from year t to year $t+1$, and $d(L_{i,t}, L_{i,T})$ is the distance that city i moved from year t to the last year. The larger the value of N, the longer the movement length and the more dynamic the local spatial dependency and local spatial structure (i.e., the migration path is less stable). As the value of D increases, the curvature increases, the local spatial dependency direction and fluctuating growth process become more dynamic, and the fluctuation over time becomes more severe; however, the opposite results in a reduced impact with a more stable fluctuation.

2.2.6. Spatio-Temporal Prediction Integrated Model

Spatio-temporal comprehensive prediction refers to modelling the change in the trends of time and space attributes using different methods according to different data characteristics. The core of the algorithm is spatio-temporal synthesis, which considers both the target object and the influence of adjacent objects. The time series prediction time relationship and the autoregressive integrated moving average (ARIMA) model were used to obtain the time series prediction data from 2021 to 2030. The ARIMA model is a time series prediction method with high accuracy based on the stochastic theory proposed in the Box–Jenkins model [32]. A neural network was established to predict the spatial relationship, and the artificial neural network was used to determine the hidden spatial correlation between all spatial location data. To calculate the stable and reliable spatial relationships, the artificial neural network can be used to learn hidden patterns and relationships. The MATLAB neural network was used for model training, and the time series data predicted by the ARIMA model were then input to obtain the spatial prediction impact results. The time and spatial predictions were combined to determine the final spatio-temporal comprehensive prediction. Furthermore, averaging is the simplest comprehensive method and may be more efficient for the actual data [33].

3. Theory

3.1. Establishing a System for Describing the Conceptual Model

A system is a set of interrelated elements. Studying the problem from a systems perspective may allow for an optimised and comprehensive determination of the problem and an accurate understanding of the ecological economy of sea–land integration. Furthermore, the sea–land economy is a system structure comprising several sub-system elements within a complex system [34–37]. Industrial integration is a trend in economic development, and its formation requires open systems as a prerequisite as well as innovation as an opportunity, competition and collaboration between subjects, co-evolution between elements, and other external factors that contribute to the integration process. The economic integration of land and sea is attributed to the change in strategic thinking and the advancement of science and technology. Furthermore, the economic relationship between land and sea is closely linked, fundamentally owing to the coexistence and mutually beneficial relationship between sea and land industries. Furthermore, the layout of the industries requires both a marine resource supply and land area as a base; production factors need to flow between sea and land areas and among industries [38–40].

Considering industrial integration as a new starting point for the sea–land economy and using systems theory as a research framework to propose an ecological economy of sea–land integration is consistent with the research process of the sea–land economy, drawing from previous studies on sea–land coordination and sea–land economic links but varying from both [41,42]. Sea–land coordination focuses on ideological connotations, overall planning, and coordinated development, whereas sea–land economic links emphasise the reduction in common barriers and obstacles in specific sea–land industrial development links for the joint development of the sea–land economy. Based on the development of economic links, increased international division of labour and socialised mass production have moved national economies from the original economic exchanges to economic cooperation and economic integration. The integration of sea and land is beneficial for the evolution of the entire economic system, particularly to meet the objective of carbon neutrality and peak emissions.

The integration of marine and terrestrial ecological economies necessitates that the economic structure must change; the crossover, integration, and penetration among the elements of the system must evolve into new elements after integration in a new economic model. The organisation and coordination between the elements within the system must also change. These changes will allow the achievement of optimal allocation, which will bring multiple elements to power and promote multiple models, multi-mechanism linkages, multi-industry creation, and economic vitality (Figure 2). These factors are non-linearly correlated and affect the process of integrating land and sea economies, primarily in the form of different production methods and development plans owing to the differences in resource conditions and different development models due to the economic base and advantages of the subjects. In the systems framework, the concept of viscosity is introduced to interpret the ecological economy of sea–land integration and build an indicator system. Viscosity refers to a macroscopic property of real fluids, and there are similarities between physical fluids and land–sea convergence economies based on a linkage perspective [43]. During economic convergence, the connections and constraints within the system form the interaction force within the subject, which organises the system. Although this study refers to a land and sea integration economy that differs from those in previous studies, the phenomenon and essence of the integration economy are consistent with the principles revealed by the theory of viscosity in physics [44].

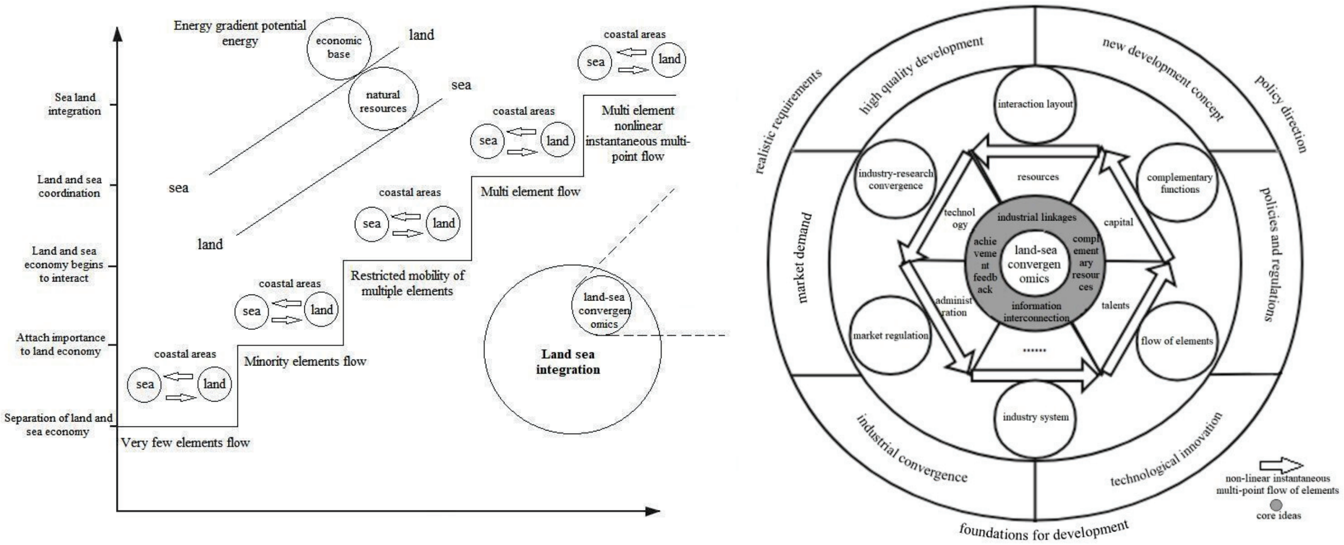

Figure 2. Conceptual relationship of the sea–land integration economy and evolution of the related development context. Source: own elaboration on the basis of 3.1 Chapter literature and theory.

3.2. Establishing a System for Assessing the Integration Capacity of Marine and Terrestrial Ecological Economies

The analysis of the conceptual model confirms the suitability of introducing the concept of viscosity into the ecological economy of the sea–land integration system. The interaction of the intrinsic elements of land and sea economic agents, resource use and conservation, technological innovation, economic linkage mechanisms, and social development outcomes indicate the development of an integrated system of land and sea economies. By organising and analysing the relevant literature and combining the practice of the sea–land economy, the development process of the sea–land-integrated ecological economy comprises a four-part systematic framework: the basis of integrated economic development, integrated economic resource development, integrated economic industry linkage, and integrated economic outcome creation.

The following system of indices was constructed by incorporating the concept of viscosity into land–sea convergenomics. Consequently, 23 indices were selected for the creation of a comprehensive system of indices that adequately reflected every aspect of the convergence of land and marine economies. The selection criteria for the indices included scientific reproducibility, mutual independence, and measurability (Table 1). With respect to the literature, this study primarily refers to the indicator system reported by Di and Han [45]. The study applies the systemic framework and the viscosity concept and attempts to reflect the purpose of the joint role of cities and oceans, focusing on both comprehensiveness and representativeness in important links [46]. We sought to create an evaluation system comprising 23 indicators combined with quantifiable and available data.

Regarding indicators included in Table 1, the basis of integrated economic development is the basic condition for the development of a sea–land-integrated economy, which provides basic support for the integrated economy and directly affects its future development space and scale. Herein, we adopted the gross domestic product (GDP) of sea and land areas, their respective shares in GDP, and the entropy of sea–land industrial location as the indicators of the current level of economic development and its status in regional economic development. The development of integrated economic resources is an important part of the economic development of sea–land integration. By managing the abundance of marine and land resources, the environment, and ecology, resources that promote sea–land economic development are transformed. We first measured the abundance of marine and land resources using four indicators of resource abundance: greenfield area, area in which crops are sown, production of marine products, and mariculture area. Subsequently, the pressure and carrying capacity of sea and land environments were used to express the state of the sea and land environments, the content of which includes the proportion of four inferior types of seawater, the amount of industrial solid waste generation to express the pressure level, and the environmental quality and seawater pollution absorption capacity as an expression of the carrying capacity. Notably, high-tech and resource development capacity are essential in the development of a sea–land-integrated economy and thus are the two vital indicators of the level of resource development, sea and land science and technological innovation capabilities, research and technology services, and geological exploration practices. In contrast, the energy consumption value of 10,000 Yuan as GDP and the GDP growth rate are the indicators of development capacity and power. The core linkage of the integrated economy is the development of the sea–land-integrated economy. The integration of resources improves the organisation of efficient logistics and industrial linkage, circulation of finished products, and industrial interaction. There are three indicators of the logistics level: port cargo throughput, road freight volume, and access to the transport network (road area per capita). The sea–land industry linkage effect value is a measure of industries' ability to interact, and it comprises a ratio of the amount of change in the marine-based industry to the amount of change in the land-based industry, that is, reflecting the difference in the rate of change between the two in a natural year. The integration of economic outcome creation is an inevitable requirement for the development of a land and sea integrated economy. Labour and assets are also essential for the development of a land and sea integrated economy, which must consequently benefit society. This study considers urban registered unemployment as the labour force participation indicator, the amount of investment in fixed assets in marine and land areas as the capital participation indicator, and two indicators of the urbanisation rate and quality of life to express social development level.

Table 1. System for assessing the development of a city's capacity to integrate its marine and terrestrial ecological economies. Source: the data sources used in this study include the 2010–2020 editions of the China Marine Statistical Yearbook, China City Statistical Yearbook, Shandong Statistical Yearbook, Liaoning Statistical Yearbook, Hebei Economic Yearbook, Tianjin Statistical Yearbook, Bulletin on Environmental Quality of China's coastal waters, and the statistical bulletins of the relevant national departments.

Target Layer	System Layer	Index Layer
Capacity to integrate the marine and terrestrial ecological economy	Basis of development fundamentals (OI)	Gross oceanic product (GOP)
		Share of GOP in GDP
		Gross terrestrial product (GTP)
		Share of GTP in GDP
		Location entropy of the maritime industries
		Location entropy of the terrestrial industries
	Integrated economic resource development (OC)	Extent of resource abundance
		Marine and terrestrial environmental pressure
		Marine and terrestrial environmental carrying capacity
		Level of resource development
		Resource development capacity
		Resource development drive
	Integrated economic industry linkage (OE)	Port cargo throughput
		Road cargo transport volume

Table 1. *Cont.*

Target Layer	System Layer	Index Layer
	Integrated economic outcome creation (OU)	Accessibility of transportation networks Primary sector linkage effect values for sea and land Secondary sector linkage effect values for sea and land Tertiary sector linkage effect values for sea and land Urbanisation rate Urban registered unemployed persons Marine fixed asset investment Terrestrial fixed asset investment Life quality index

4. Results

Through data collection and processing, the overall characteristics of the development level of the sea–land integrated ecological economy in cities around the Bohai Sea were described and analysed. Its evolution process was analysed via spatio-temporal autocorrelation and time path methods, and its development trend was forecasted and analysed using the spatio-temporal prediction model.

4.1. Integration Capacity Values of Cities in the Bohai Rim

Based on the measurement model and evaluation index system of the development level of the sea–land integrated ecological economy, the development level of the sea–land-integrated ecological economy in cities around the Bohai Sea from 2009 to 2019 and the proportion of each city at the system level were obtained, as presented in Table 2 and Figure 3. This revealed the overall characteristics of the development level of the sea–land-integrated ecological economy in cities around the Bohai Sea.

Table 2. Integration capacity values of cities in the Bohai Rim (2010–2019). Source: own elaboration on the basis of a system for assessing the development of a city's capacity to integrate its marine and terrestrial ecological economies and formula (1), (2), (3), (4).

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Average
Dalian	0.2887	0.3281	0.3983	0.4473	0.4580	0.4055	0.3559	0.3804	0.4166	0.3425	0.3821
Yingkou	0.0395	0.0414	0.0517	0.0578	0.0648	0.0624	0.0579	0.0642	0.0632	0.0573	0.0560
Panjin	0.0242	0.0265	0.0315	0.0372	0.0430	0.0419	0.0412	0.0368	0.0414	0.0421	0.0366
Jinzhou	0.0306	0.0372	0.0402	0.0446	0.0492	0.0458	0.0430	0.0496	0.0480	0.0465	0.0435
Huludao	0.0195	0.0213	0.0271	0.0298	0.0293	0.0306	0.0305	0.0343	0.0376	0.0364	0.0296
Dandong	0.0281	0.0330	0.0342	0.0402	0.0423	0.0423	0.0364	0.0453	0.0413	0.0377	0.0381
Qinhuangdao	0.0445	0.0498	0.0523	0.0554	0.0618	0.0621	0.0610	0.0632	0.0658	0.0625	0.0578
Tangshan	0.1093	0.1318	0.1563	0.1940	0.2028	0.2158	0.2419	0.2628	0.2919	0.3395	0.2146
Cangzhou	0.0506	0.0608	0.0670	0.0854	0.0893	0.0871	0.1130	0.1256	0.1440	0.1557	0.0979
Tianjin	0.3368	0.4110	0.5312	0.6576	0.7510	0.8419	0.8738	0.8834	0.8729	0.8331	0.6992
Binzhou	0.0365	0.0459	0.0493	0.0584	0.0546	0.0577	0.0645	0.0711	0.0744	0.0674	0.0580
Dongying	0.0449	0.0496	0.0573	0.0708	0.0791	0.0826	0.0825	0.0947	0.1005	0.0910	0.0753
Weifang	0.0723	0.0846	0.1050	0.1254	0.1382	0.1330	0.1550	0.1728	0.1863	0.1778	0.1350
Yantai	0.1599	0.1783	0.2027	0.2259	0.2533	0.2694	0.3127	0.3532	0.3916	0.3720	0.2719
Weihai	0.0816	0.0868	0.1002	0.1140	0.1174	0.1268	0.1500	0.1565	0.1589	0.1478	0.1240
Qingdao	0.2245	0.2680	0.2775	0.3525	0.4043	0.4127	0.4638	0.5193	0.5884	0.6580	0.4169
Rizhao	0.0327	0.0374	0.0410	0.0546	0.0575	0.0628	0.0745	0.0828	0.0901	0.0901	0.0624

Table 2 shows that, from 2009 to 2019, the development level of the ecological economic sea–land integration in Bohai Rim cities was generally increasing; however, the magnitude varied significantly between cities. The value of the development level of ecological economic sea–land integration in Bohai Rim cities ranged from 1.333 to 3.613 and increased from 2009 to 2018, with a slight decrease in 2019. Although the trends of all cities increased, each city exhibited a different starting point and rate of increase, with some cities showing a large fluctuating upward trend, most cities showing a small fluctuating rise, and all cities ranging between 0.017 and 0.186, including Weifang, Weihai, Cangzhou, Dongying, Rizhao, Binzhou, Qinhuangdao, Yingkou, Jinzhou, Dandong, Panjin, and Huludao—all cities with a high starting point. The cities that exhibited a large increase included Tianjin, Qingdao, Dalian, Yantai, and Tangshan, with Tianjin exhibiting the highest value among cities. This value increased to 0.883 after 2011, until 2017 when it slightly dropped. Qingdao and Dalian exhibited an upward trend during the early stage; however, after 2014, the Dalian value began to fluctuate more. After 2015, Qingdao surpassed Dalian and continued to stabilise. After 2015, Qingdao surpassed Dalian and continued to grow steadily until it reached 0.658. Despite a slight increase, the subsequent value for Dalian significantly differed from that for Qingdao. Furthermore, in 2019, when the level of most cities declined, Dalian was surpassed by Yantai and was almost on par with Tangshan. Figure 3 shows that in terms of the proportion of each city's effectiveness in the sub-system layer, the integration economy development foundation layer remained high and increased steadily. The integrated economy resource development layer had a low value of effectiveness and grew gradually; the integrated economy industry linkage layer exhibited the highest growth and the highest value of effectiveness but with small fluctuations. The integrated economy outcome creation layer had a low starting point but remained relatively stable and then exhibited rapid growth. Among the systems, the development base was relatively stable, level of resource development was low, industrial linkage effectiveness value was high and rapidly developing, and outcome creation was influenced by the first three to show a comprehensive low level of rapid growth. In the proportion of cities in each system in each year, the cities with a high starting point and a large increase in the level of development of the ecological economy of land and sea integration were Tianjin, Qingdao, Dalian, and Yantai; these cities accounted for a relatively high proportion in each layer of the system. Tangshan accounted for a smaller proportion than the four aforementioned cities in the development of resources and the creation of outcomes but accounted for a larger proportion in industrial linkages and an increasing proportion in the creation of outcomes, indicating that this city plays a more optimised role in industrial linkages and makes full use of its benefits.

Summary of considerations: the development of the sea–land-integrated ecological economy of Bohai Rim cities was not optimal, and most cities were at a low level. The gap between cities was too large; only a few large cities exhibited a high and rapid growth trend, and most cities exhibited a low trend and gradual growth. The development of a sea–land-integrated ecological economy was too dependent on the original foundation of the city, thereby not allowing for the exploration of new development models, innovation, and a resource development system layer. The low efficiency and gradual growth of the systemic layer of resource development suggest that the focus on science, technology, and the environment has to be enhanced. To better investigate the changing characteristics and development patterns of the sea–land-integrated ecological economy of Bohai Rim cities, further map visualisation analysis was performed on the spatial changes of the hierarchy of the sea–land-integrated ecological economy of Bohai Rim cities from 2009 to 2019.

4.2. Spatio-Temporal Autocorrelation in Integration Capacity

It is necessary to further explore the spatio-temporal characteristics of the development of the sea–land integration eco-economy in cities around the Bohai Sea to comprehensively explain its regional aggregation and heterogeneity. Therefore, spatio-temporal autocorrelation analysis was conducted on the development level of the sea-land integration eco-economy in cities around the Bohai Sea, and the correlation pattern of its development was studied from a spatio-temporal perspective. Data analysis was conducted using the development level of the sea-land integration eco-economy in cities around the Bohai Sea (Table 2).

4.2.1. Global Spatio-Temporal Autocorrelation

The global spatio-temporal autocorrelation Moran's I index was obtained by substituting the values of the level of ecological and economic development of the Bohai Rim cities into Equation (5) (Table 3).

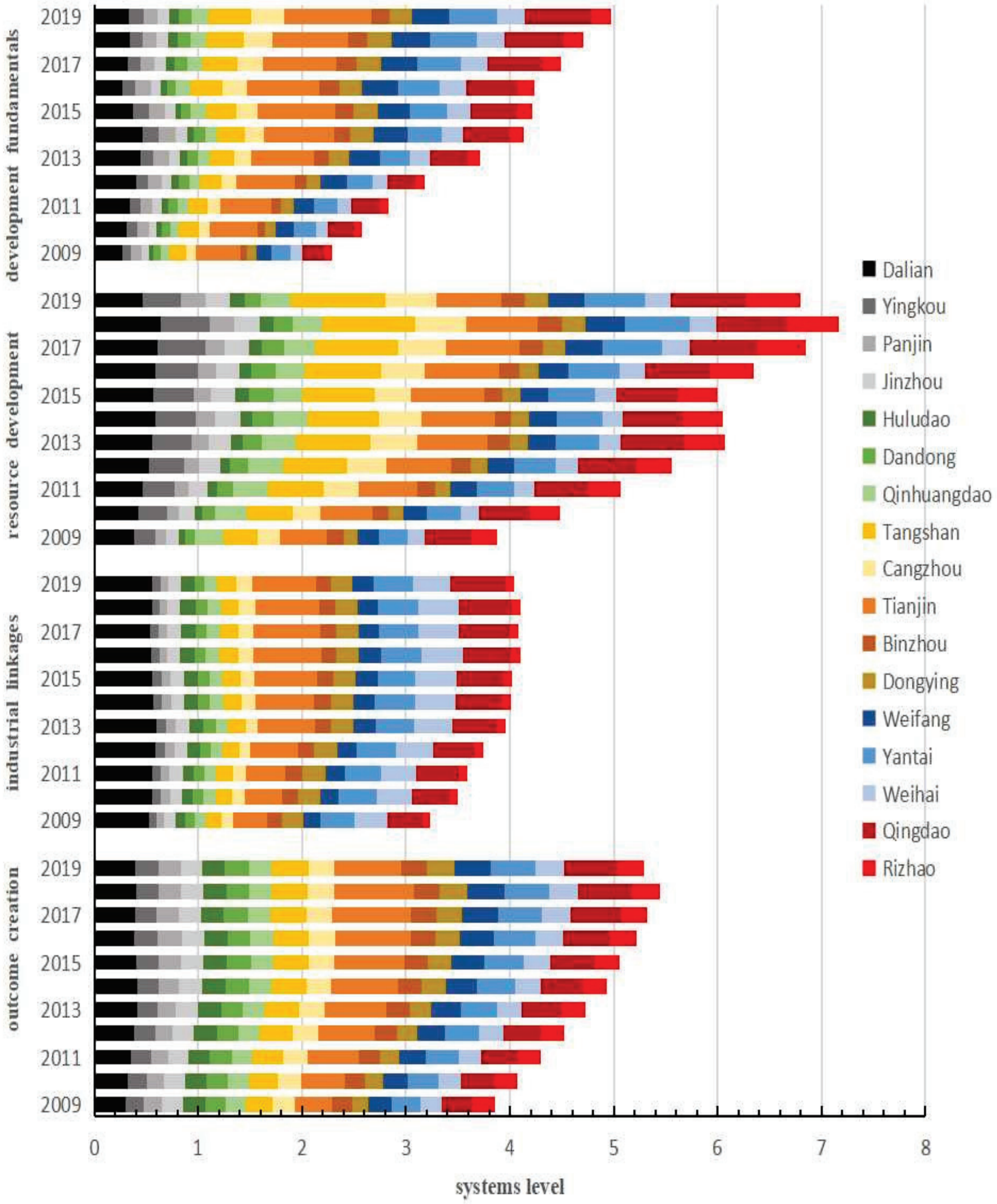

Figure 3. Proportion of Bohai Rim city system-level index (2009–2019). Source: own elaboration on the base of a system for assessing the development of a city's capacity to integrate its marine and terrestrial ecological economies and formula (1), (2), (3), (4).

Table 3. Global spatio-temporal Moran's I of the integration capacity between the marine and terrestrial ecological economies. Source: own study.

T + k **t**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
2011	−0.0706	−0.0603	−0.0541	−0.0314	0.0060	0.0145	0.0210	0.0509
2014				−0.0319	0.0044	0.0117	0.0186	0.0520
2016						0.0442	0.0521	0.0894
2018								0.1027

The overall index changed from negative to positive spatio-temporal correlation (i.e., from spatio-temporal heterogeneity to spatio-temporal aggregation), with negative spatio-temporal correlation dominating until 2014 and positive spatio-temporal correlation after 2014 (i.e., showing a high or low spatio-temporal aggregation pattern). As shown in Table 3, the Moran index gradually increased as the time step between 2011 and 2018 increased, and the influence of moment t on moment $t + k$ increased as the value of k increased. The level of ecological and economic development of sea–land integration reached new peaks in 2018 and 2019, with a positive effect on the overall mutual and coordinated development of the region. However, firstly, the distribution of cities around the Bohai Sea is primarily in the form of a belt structure owing to topographical factors, and secondly, the number of cities in the study sample is limited.

4.2.2. Local Spatio-Temporal Autocorrelation

The global spatio-temporal autocorrelation index analyses revealed the overall regional spatio-temporal association pattern of the Bohai Rim cities' sea–land-integrated eco-economy (Figure 4). However, the spatio-temporal associations among cities within a specific region could not be explored and thus require further analysis using a local spatio-temporal autocorrelation index.

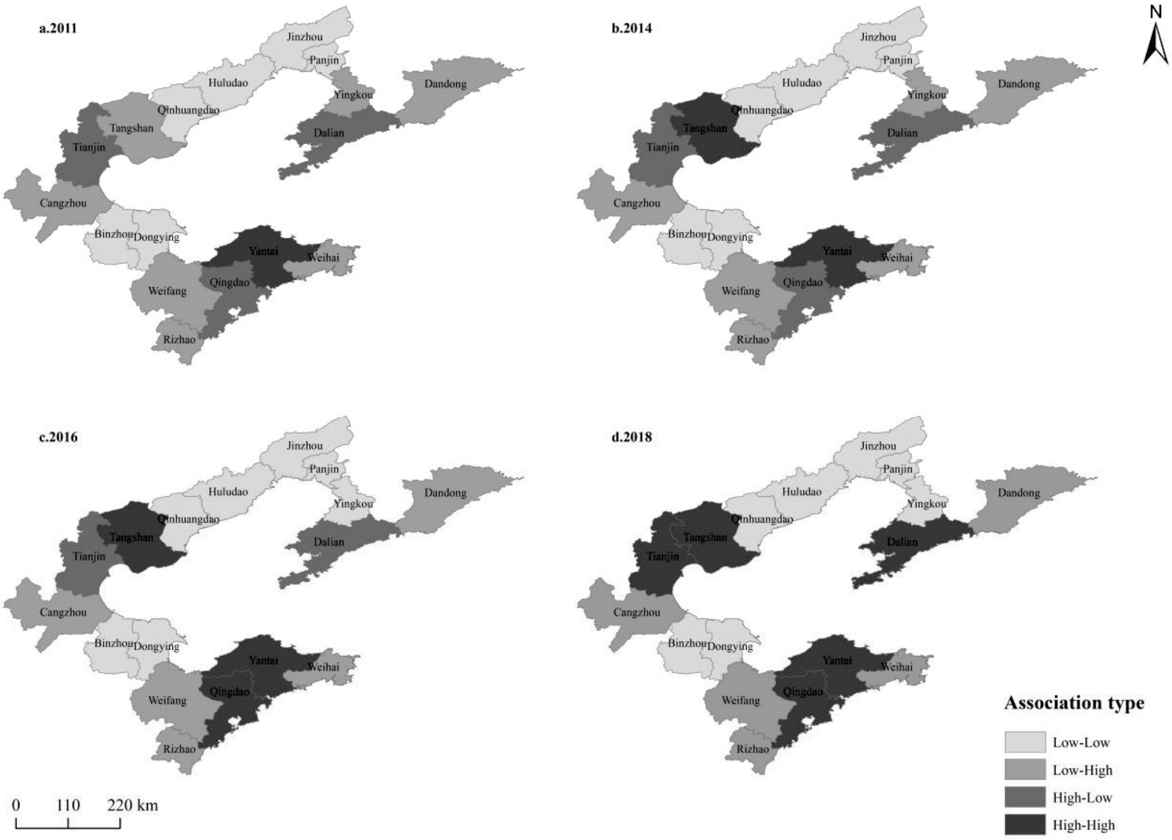

Figure 4. Local spatio-temporal Moran's I of the sea–land integration ecological economic development level of cities around the Bohai Sea. Source: own study.

In terms of relative length (Figure 4), during the study period, Yantai maintained the H–H spatio-temporal association and a more stable agglomeration effect. In 2011, Dalian, Qingdao, and Tianjin exhibited the H–L type of association, indicating that big cities had not formed a kind of agglomeration drive at the time. The surrounding cities remained in the L–L type or L–H type. In 2018, three H–H type agglomerations were formed in the north, centre, and south, containing Dalian, Tianjin, Tangshan, Qingdao, and Yantai as the central cities. The distribution of the L–L type associations was relatively stable and followed the line from Qinhuangdao to Yingkou, including the two adjacent cities of Binzhou and Dongying. Only Yingkou was of the L–H type before 2014 and became L–L after 2018, a phenomenon that indicates the reduced aggregation effect of adjacent large cities. The distribution of cities in the local spatio-temporal heterogeneity H–L and L–H types was more dispersed and relatively variable, with Qingdao in 2016 and Dalian and Tianjin in 2018 entering the H–H type association from the H–L type. These three cities are surrounded by the dispersed distribution of Dandong, Cangzhou, Tangshan, Weifang, Rizhao, and Weihai, L–H type cities, with Tangshan entering the H–H type association from the L–H type in 2014.

Summary of considerations from the spatial-temporal autocorrelation analysis of the development level of the sea-land integration ecological economy in cities around the Bohai Sea: First, the global spatiotemporal autocorrelation index of cities around the Bohai Sea changed from negative to positive spatio-temporal correlation (i.e., from spatio-temporal heterogeneity to spatio-temporal aggregation). Secondly, the spatio-temporal association pattern of cities around the Bohai Sea (H–L and H–H types) changed frequently, whereas the rest of the spatio-temporal units did not change significantly. The development of the sea and land integration ecological economies of cities around the Bohai Sea basically formed three major agglomerations, with Dalian in the north, Yantai and Qingdao in the south, and Tianjin and Tangshan in the centre as the core cities. However, it also contains the L–L type area along the line from Qinhuangdao to Yingkou, Binzhou, and Dongying, and L–H type spatio-temporal heterogeneous units attached to the dispersed distribution of H–H type cities. Therefore, large cities should strengthen their agglomeration effect and develop their role as a radiating force for the surrounding cities, creating an integrated economy that is efficient, energy-saving, green, technological, and dynamic.

4.3. Analysis of Spatio-Temporal Dynamic Patterns in Terms of Integration Capacity

The LISA time path is based on the temporal migration of LISA coordinates in a Moran scatter plot. The spatio-temporal cooperative changes within the local area of elements are described, and the spatio-temporal dynamics of their local spatial differences were determined. The GeoDaV1.20 operation programme was used to output LISA coordinates of the development level of sea–land integration ecological economy in cities around the Bohai Sea based on the original data of the sea–land integration economy in cities around the Bohai Sea (Table 2).

4.3.1. LISA Time Path Geometry Features

LISA time path analysis was carried out for two time periods: 2010–2014 and 2015–2019, using Equation (5). The results were normalised to low relative length (low curvature), moderately low relative length (moderately low curvature), moderately high relative length (moderately high curvature), and high relative length (high curvature). ArcGIS 10.2 software was used to visualise the relative length (curvature) of the LISA time path (Figures 5 and 6).

In terms of relative length (Figure 5), the local spatial structure of the ecological economy of sea–land integration in Bohai Rim cities was highly stable. Panjin was a high relative length city in 2010–2014 and was highly unstable. Dandong, Dalian, Tianjin, and Qingdao had a moderately low relative length and more stable local spatial structure; most cities were of low relative length and had a highly stable local spatial structure. The number of cities with high relative lengths remained relatively unchanged from 2015 to 2019; however, Qingdao and Panjin significantly shifted to have low relative lengths. Dandong, Dalian, and Tianjin shifted to a moderately high relative length, and Yingkou, Tangshan, Cangzhou, Rizhao, Yantai, and Weihai shifted from low relative lengths to moderately low relative lengths. Qingdao, Tianjin, and Dalian shifted to moderately high relative lengths and high relative lengths, and the local spatial structures had a strong dynamic in which their aggregation effects increased, further contributing to their driving radiative role to surrounding cities which have low relative lengths (from 12 to 7), primarily including Tangshan, Yingkou Line, Cangzhou, and the Rizhao region. The local spatial structure in these cities was the most stable, primarily because these cities have a similar urban base.

The low and moderately low relative lengths were 15 and 13 in the two periods, indicating that the Bohai Rim is an area with a stable ecological and economic local spatial structure of land and sea integration.

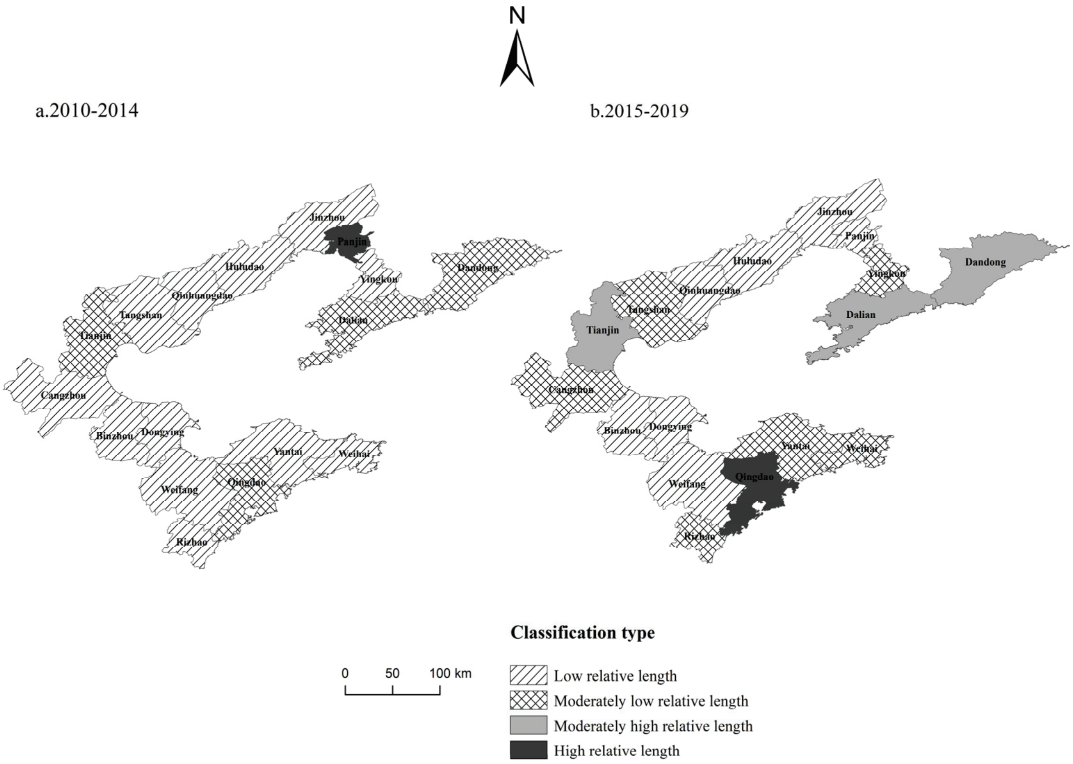

Figure 5. Relative length of the local indicators of the spatial association time path. Source: own study.

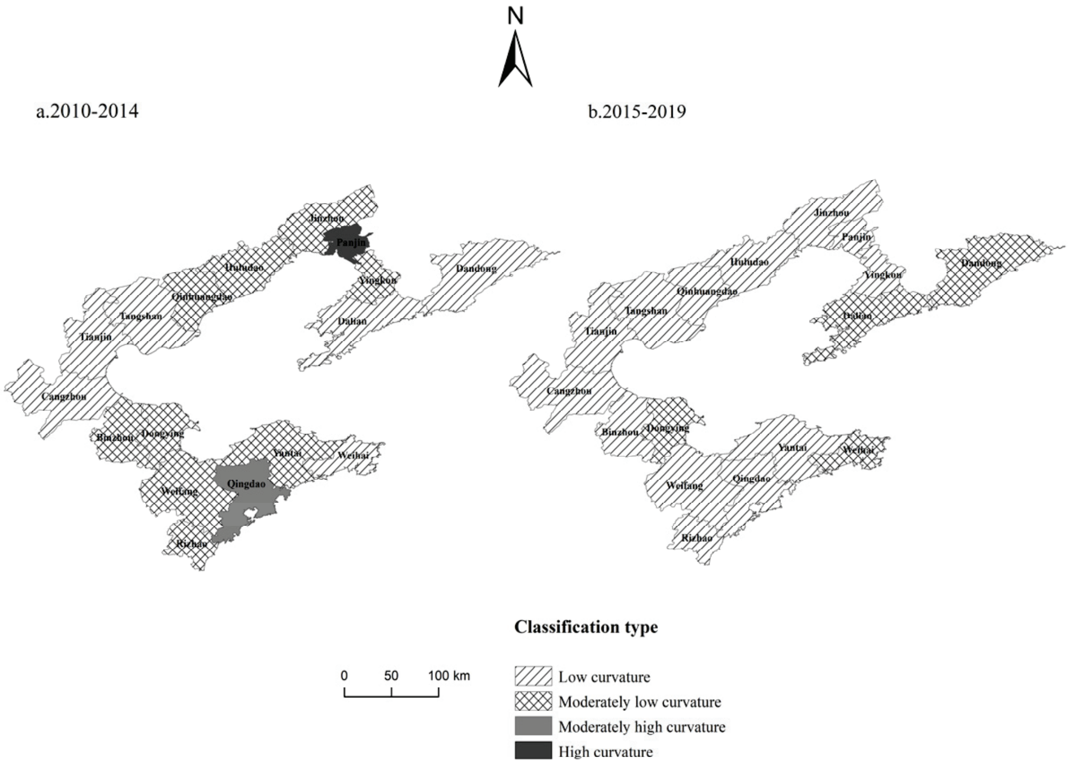

Figure 6. Tortuosity of the local indicators of the spatial association time path. Source: own study.

In terms of curvature (Figure 6), the process of local spatially dependent change in the ecological economy of sea–land integration in cities around the Bohai Sea is stable. From 2010 to 2014, Panjin, a high-curvature city, had the most volatile process of local spatial dependence; Qingdao, a moderately high-curvature city, had more volatile growth and local spatial dependence; Dandong, Dalian, Tangshan, Tianjin, Cangzhou, and Weihai, low-curvature cities, had the most stable growth and local spatial dependence; and the remaining cities were all moderately low-curvature. From 2015 to 2019, Dalian, Dandong, and Weihai evolved into moderately low-curvature cities; the number of low-curvature cities increased from 6 to 13, showing an upward trend. Regarding spatial distribution, high curvature and moderately high curvature cities disappeared, and low curvature cities showed a clear trend of contiguity in their spatial distribution.

4.3.2. LISA Time Path Transfer Direction

The LISA time path movement directions can be used to reveal the spatial integration characteristics of the changes in the local spatial patterns of geographical elements. By comparing the positions of Moran's I scatter diagrams in 2010, 2014, 2015, and 2019, the movement directions of LISA coordinates in Bohai Rim cities were calculated and classified into four categories, among which 0–90° was the mutually beneficial type, indicating a synergistic positive growth trend of geographical elements in a region and its neighbouring regions; 90–180° and 270–360° were lose–win and win–lose types, respectively, indicating a reverse growth trend; and 180–270° was a lose–lose type, indicating a synergistic negative growth trend. The results are shown in Figure 7.

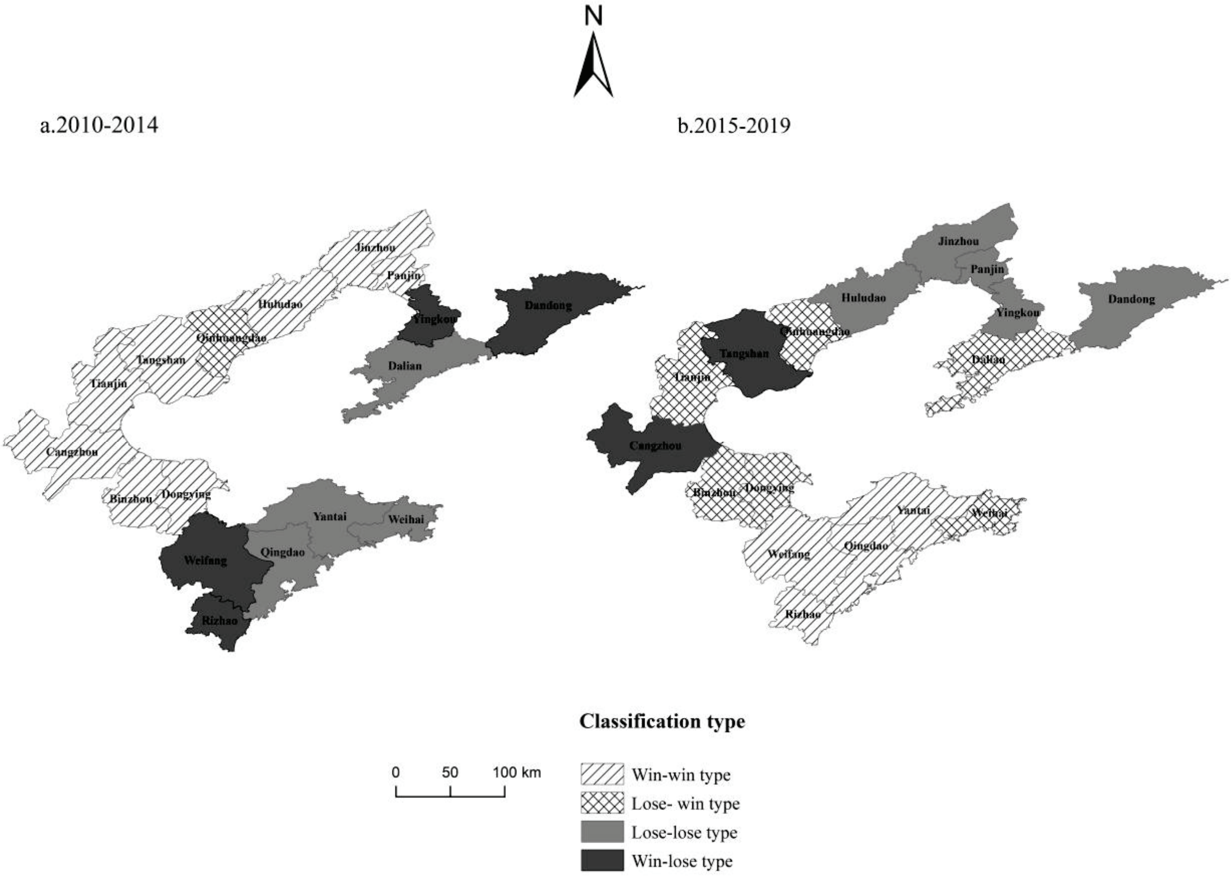

Figure 7. Movement direction of the local indicators of the spatial association time path. Source: own study.

In terms of the direction of the LISA shift (Figure 7), the spatial integration of the Bohai Rim cities in the spatial pattern of the ecological and economic integration of land and sea is decreasing, and the pattern of synergy and competition is increasingly prominent. From 2015 to 2019, the number of mutually beneficial cities decreased to four, and they were located in Shandong with an overall shift to the south, where the cities exhibited relatively rapid development. Five cities were lose–lose, with a spatial distribution that shows a spreading trend to the north. The number of cities with coordinated growth declined from 8 in 2010–2014 to 4 in 2015–2019, indicating a shift from a synergistic growth-led ecological economy to a pattern of synergy and competition and a decline in spatial integration in Bohai Rim cities.

Summary of considerations from analysing the development level of sea-land integration ecological economy in cities around the Bohai Sea through the exploratory spatio-temporal data analysis model: First, in terms of relative length, the Bohai Rim is an area with a stable ecological and economic local spatial structure of land and sea integration. Secondly, in terms of curvature, the process of local, spatially dependent change in the ecological economy of sea-land integration in cities around the Bohai Sea is stable. Last, in terms of the direction of the LISA shift, a shift from a synergistic growth-led ecological economy to a pattern of synergy and competition and a decline in spatial integration in Bohai Rim cities is indicated.

4.4. Predicting Trends in the Development of Integration Capacity

The MATLAB 9.0 software suite was used to develop a spatio-temporal prediction programme model for the level of the ecological economy of marine and terrestrial integration of each Bohai Rim city. The MATLAB programme was verified and executed in a MATLAB window. The predictions were based on the integration level data for Bohai Rim cities as shown in Table 2. The predictions are depicted in Figure 8. Before predicting, the data had to be validated, and the programme was only executed after verifying the feasibility of the modelling method.

The prediction results of the operation output show that the development level range was [0.86, 0.034] from 2020 to 2029, which is a development period (Figure 8). During this period, the development gap between cities around the Bohai Sea increases; however, most cities exhibit an upward trend, indicating that the current series of measures for marine economic development are conducive to integrated development. However, different cities have different rising ranges and a significant gap. In the past, the gap gradually widened, such as in Panjin, Jinzhou, and Huludao. The forecast value of Dandong was low, and those of Weifang, Cangzhou, Tangshan, and Yantai sharply increased. The values for Tianjin and Dalian exhibited a fluctuating trend; however, they always maintained a high level. Qingdao maintained a stable growth trend and a high level of integration.

The predicted development level of economic integration between sea and land in Bohai Rim cities is divided into three levels: the high-, medium-, and low-value zones. As shown in Figure 8, the high-value zone contains Qingdao, Tianjin, Yantai, Tangshan, Dalian, Weifang, and Cangzhou, with fluctuations primarily between 2023 and 2026, Yantai and Tangshan increasing more than Tianjin, Tianjin decreasing and then increasing again, and Qingdao maintaining a high level. The medium-value zone contains Weihai, Rizhao, Dongying, Binzhou, and Qinhuangdao, with fluctuations primarily between 2023 and 2026. In 2023–2025, the development level of Rizhao exceeds that of Weihai, whereas that of the other cities remains relatively stable. The low-value zone contains Yingkou, Panjin, Jinzhou, Huludao, and Dandong, and it has a smaller overall value range and smaller fluctuation areas. In the low-value zone, Huludao increases more than Jinzhou and Panjin during 2021–2023, Yingkou declines, and Dandong and Huludao increased from 2015–2018. Overall, the forecasted values for the level of economic integration between sea and land in Bohai Rim cities maintained the trend and pattern of the original study period, with several high-value cities remaining at a high level and some cities having smaller differences between fluctuations.

Summary of considerations seen from the predicted value of development levels: The development gap between cities around the Bohai Sea increased; however, most cities exhibited an upward trend. These results call for attention to the development of the sea and land economies of big cities and the surrounding cities to ensure balance in large regions. Notably, the sea and land economic development of big cities should play a leading role in maintaining the steady growth of the integration level and contributing to the steady progress of the regional sea and land economies.

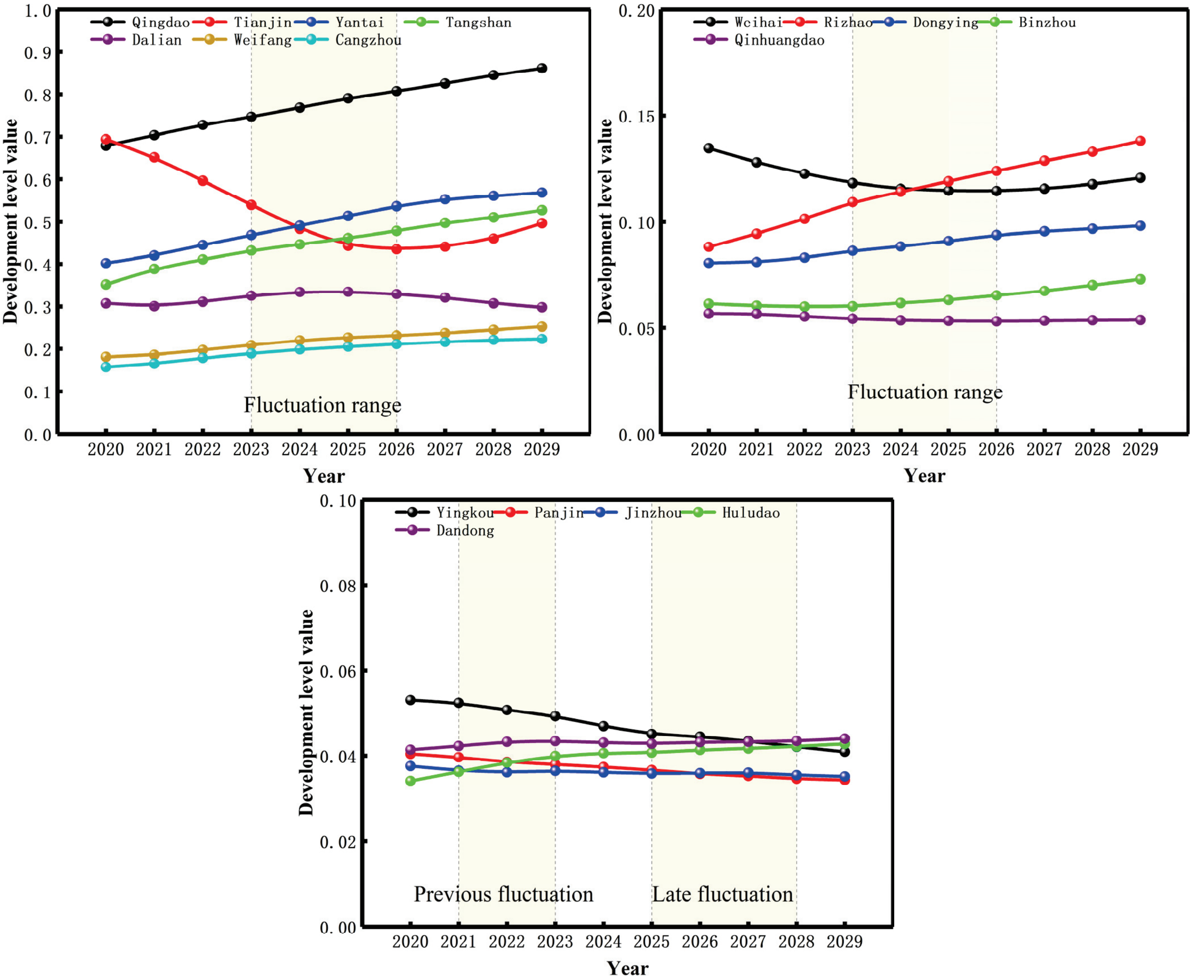

Figure 8. Prediction value of the integration capacity of each city in the Bohai Rim (2020–2029). Source: own study.

5. Discussion

A series of analyses showed that the sea–land integrated ecological economy of Bohai Rim cities is not optimal and that most cities are at a low level of slow growth; only some large cities exhibit high and rapid growth. The development of the ecological economy of a city's land and sea integration is dependent on the city's original economic resources and transportation, among other foundational factors; new development models and innovation cannot be explored, and the resource development system layer level is low and has slow growth. These factors indicate the need for improvements in science, technology, and the ecological environment.

The development of the ecological economy of sea–land integration in cities around the Bohai Sea has resulted in the formation of three major radiation circles with Tianjin, Qingdao, and Dalian as the core cities, indicating the need to strengthen the radiation role of the core cities. According to the actual situation of the core cities and the surrounding cities, we could enhance the economic development of sea–land integration and better promote the high-quality development of the sea–land economy.

The analysis of a spatio-temporal autocorrelation model shows that the interconnection and establishment of cooperation and communication between the regions of the sea–land-integrated ecological economy in the early stages of development is crucial for ultimate mutual development. Regional differentiation leads to a complexity of changes in spatial and temporal associations. However, positive and negative spatio-temporal effects indicated by Moran's I and the spatial complexity of the distribution of each city indicate that the sea–land-integrated eco-economies of the Bohai Rim cities are interconnected, however, they have not formed a coordinated development model with close interconnection.

According to LISA time path analysis, the central Bohai Sea is a region with a stable local spatial structure of the sea–land-integrated ecological economy. The decline in the number of cities with coordinated growth indicates that cities around the Bohai Sea have changed from an ecological economy dominated by coordinated growth to a cooperative competition model, and the degree of spatial integration has declined.

6. Conclusions

From 2009 to 2019, the development level of the sea–land integrated ecological economy in cities around the Bohai Sea trended upward. However, significant differences were observed among cities, as each one had different starting points and incremental changes. Although certain cities showed large fluctuating uptrends, most showed small changes with low viscosity (0.017–0.186).

The global spatio-temporal Moran's I for the Bohai Rim cities changed from negative to positive spatio-temporal correlations, however, it always remained at a low level. The local spatio-temporal Moran's I and H–L and H–H types of spatio-temporal correlations significantly varied, whereas the remaining spatio-temporal units did not.

The low and moderately low relative lengths were 15 and 13 in the two periods, respectively. In terms of spatial distribution, high curvature and moderately high curvature cities disappeared, and low curvature cities showed a clear trend of contiguity in their spatial distribution. The number of cities with coordinated growth declined from 8 in 2010–2014 to 4 in 2015–2019. The prediction results of the operation output coordination degree showed that the coordination degree range was [0.86, 0.034] from 2020 to 2029, which is a development period.

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water

Article

Game of Marine Natural Resources Management: A strategy for Determining Rights Registration

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Abstract: The unified right confirmation and registration of natural resources in sea areas (URCRNRSA) has been considered a key approach to the effective management and sustainable utilization of marine resources. In China, the system of URCRNRSA is insufficient due to the lack of central auditing supervision and public participation. In this study, the mechanism of stakeholder interaction is clarified based on the game relationship among the tripartite of the central government, local governments, and the public. The evolutionary process of tripartite decision-making is simulated with an evolutionary game model. On this basis, the strategic choices of the tripartite were analyzed in the four evolutionary scenarios of high-quality URCRNRSA. It was demonstrated that the tripartite could jointly affect the URCRNRSA through cooperation-constraint, principal-agent, and incentive-compatibility relationships. The most effective, realistic, and feasible URCRNRSA strategy was the trinity system with local government high-quality rights confirming, the central government auditing as a hard constraint and the public participating as a soft constraint. The main influencing factors for the tripartite to make different strategy selections were clarified through parameter sensitivity analysis, including cost, benefit, reward, and punishment. Accordingly, the policy recommendations were put forward to ensure the stable and efficient implementation of the URCRNRSA in China.

Keywords: natural resources in sea areas of China; right confirmation and registration; resource audit; public participation; evolutionary game; evolutionary simulation

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1. Introduction

Effective management and protection of natural resources is the premise and foundation of sustainable development and utilization of natural resources in sea areas [1–3]. The natural resource right confirmation and registration system have been recognized as an effective strategy for natural resource management, which has been effectively implemented in the management of terrestrial resources in many countries [4–6]. In recent years, this system has been adopted by some coastal countries in the management of marine natural resources [7]. Aiming at the conflicts caused by the disordered development and utilization of natural resources due to uncertain property rights [8], the unified right confirmation and registration of natural resources in sea areas (URCRNRSA) has been designed as a legal system to clarify the ownership of natural marine resource property rights at multiple scales of ecosystem and governance [9,10]. Therefore, effectively coordinating the governance of socioeconomic development and ecological and environmental protection has become a crucial issue that requires urgent addressing in developing countries [11,12]. Many countries are actively trying to establish relevant infrastructure to collect national marine spatial data for supporting the right confirmation and registration [13], which is hoped to achieve sustainable utilization of natural marine resources through allocating property rights [14]. However, the redistribution or cancellation of national marine resource rights is not as simple as that of terrestrial resources, and the existing marine jurisdiction and laws are relatively new and untested [15]. It is necessary to further explore how to construct and strengthen the URCRNRSA [10].

In recent years, the Chinese government proposed the reform idea of the unified right confirmation on natural resources and ecological spaces such as waters, forests, mountains and hills, grasslands, wastelands, and mudflats [16]. The pilot work of unified right confirmation and registration of various natural resources was performed continuously. A pilot project of the URCRNRSA has been implemented to construct the cadastral survey database of sea areas and nonresident islands and to inspect the survey data results in China. The natural resources of the sea areas are different from other natural resources. The ownership of the sea areas is exercised by The State Council of China on behalf of the State, and the subject driving ownership is the Ministry of Natural Resources of China which is a department of The State Council of China. On this basis, the natural resources in sea areas are delegated to local governments, departments, units, and individuals through multi-level principal-agent relationships by the Ministry of Natural Resources of China [17]. In reality, it is difficult for a multi-level principal-agent relationship to reflect virtual state ownership due to the characteristics of the ambiguity or uncertainty of marine resources as well as the difficulty of delimitation and liquidity of the ocean. Therefore, it has become an urgent key issue how to solve the problem of the unclarified and unimplemented rights and interests of owners in the process of the URCRNRSA in China.

In recent years, a series of studies have been conducted on the right confirmation, including marine tenure rights [10,18], property rights of fishery resources [19,20], marine space property [21], water resource rights [22], agricultural land rights [23], and forestland rights [24]. It has been demonstrated that clear property rights are conducive to realizing sustainable management objectives. Moreover, supervision has been recognized as the guarantee of realizing high-quality right confirmation and registration [16]. In China, the practice of unified right confirmation and registration of natural resources is faced with many problems, including interest conflicts among stakeholders of some resources [25], incomplete registration information [26], inadequate specification of standards and norms, disputes over ownership, and inconsistent basic data [27]. Specifically, as to URCRNRSA in China, the ownership list of sea resources badly needs to be introduced for the central and local governments hierarchically to hold, respectively, and the existing design of natural resource registration should be adjusted to apply to the resources in sea areas [28]. The reason was that some local governments ignored the importance of basic data support for the right confirmation [9]. Most existing studies have proposed specific solutions to the current situation and problems at the practical level. Still, they rarely explored the problem of inadequate implementation of the rights and interests of owners due to the lack of supervision in the process of determining the URCRNRSA at the institutional level.

According to Property rights theory, the clarification of property rights is to "internalize" the externalities of public goods to promote people's management and protection of natural resources [29]. Stakeholder participation is an important factor in influencing the implementation of marine natural resources ownership [15,30]. The construction of a supervision system that covers the entire process from "entrance" to "exit" is an effective way to internalize the externalities of public goods. However, supervising the property rights of natural resources has been solely charged by functional departments of government. Their dual identities, just like being a competitor and referee at the same time, make it difficult for the government to reasonably and effectively supervise the process of the URCRNRSA [31]. The contradiction between owners and managers could be solved with the mechanism of tension and restriction among different parties to achieve the best balance between profit pursuit and public welfare [32]. Therefore, it is necessary to establish an external supervision system from the bottom up to strengthen social supervision, especially to give full play to the role of public participation in supervision so that the local government could carry out a high-quality right confirmation with the help of the public.

In terms of internal supervision, the audit of resources and the environment plays an important role in revealing the institutional barriers, obstructions, and loopholes in the aspect of resources and environmental management [33]. Chinese government emphasized the audit of leading officials' work related to natural resource assets [34]. For further constructing the natural resource asset audit system, the central audit department should conduct tracking audits and cooperative audits [35], which can help local governments clarify the status of local natural resource assets and track the changes in the ownership of natural resources [36]. A system of URCRNRSA has just been established to provide basic information and data for governments. The systems of natural resource asset assessing, accounting, and auditing were still at the level of theoretical exploration. It is urgent to construct and improve the property rights supervision of natural resources from both the theoretical and practical levels in China's sea areas. Therefore, the system of URCRNRSA could be further improved by conducting audits of natural resources in sea areas.

In terms of external supervision, it is difficult for the public to play a supervisory role due to the inadequate public supervision system. The information disclosure was not complete, resulting in the inability of the public to access the information about natural resource property rights in a timely. Furthermore, the lack of publicity and a reward system run by the government led to a weak awareness of the public's supervision of administrative behaviors related to natural resource property rights. Additionally, since no feedback channel was established, the public could not give feedback to the government when encountering problems related to the property rights of natural resources [31].

In reality, governments and the public are bounded and rational at all levels, and it takes a long time for their strategic choices to evolve to ultimate stability. Evolutionary game theory is mainly used to study the long-term game of participants in a state of imperfect rationality [37]. Scholars have conducted evolutionary game studies on natural resource registration and confirmation, public supervision, and resource asset auditing, for example, forestry rights and agricultural land rights [38,39], which revealed the starting point of and dynamic changes in a multi-agent property rights game. The impact of resource asset audits on the strategies of different entities was analyzed by constructing an evolutionary game model of multi-agent environmental governance in China [40]. In addition, the impact of public participation in supervision on the strategic choices of other entities was analyzed in view of the important role of public participation in supervision [37]. Most existing studies were confined to the single perspective of resource right confirmation, resource auditing, or public participation and supervision, and they rarely linked the three. Additionally, there was no research on the URCRNRSA of China.

Above all, the theoretical and practical exploration of natural resource right confirmation and registration provides theoretical support and inspiration for the research related to marine resources. To speed up the establishment of the URCRNRSA system in China, in this study, the following two innovative attempts were made: (1) The analytical framework for the URCRNRSA was constructed, which included three levels of the central government, local governments, and the public, on the basis of the resources asset audit system and the public participation system for the purpose of comprehensively interpreting the interactions among these three entities. (2) In order to achieve the high-quality URCRNRSA, the evolutionary strategy path of the high-quality right confirmation and registration is theoretically explored by analyzing the costs and benefits of each entity's strategic choice in different situations and identifying the main factors influencing the tripartite strategic choice.

2. Theoretical Analysis and Model Assumptions

2.1. The Interaction Mechanism between the Central Government and Local Governments Based on the Cooperation-Constraint Relationship

Theoretically, there may exist a cooperation-constraint relationship in the URCRNRSA between the central government and local governments, which corresponds to the central government's entrusted agency and supervision behaviors of local governments, respectively (Figure 1). The central government, a party whose own interests are consistent with the general welfare of society [41], constructs the system of URCRNRSA from a long-term perspective. The local governments, as the main executor of the economic development of local resources, take the initiative to promote every project and decision that is conducive to the development of the economy, society, and environment. Specifically, the central government may be constrained by the hidden actions and hidden information of the agents because the central government's authority is delegated to local governments, departments, and units through layers of principal-agent relationships [42]. For example, some departments and units, due to their "short-sighted" consideration of short-term interests or private interests, complete the right confirmation with low standards in the process of right confirmation or pass the responsibility to each other when multi-department cooperation is involved. Some departments and units may even be unable to point out and sign for the right because they are not familiar with the specific natural resources management and current situation [26]. Due to severe information asymmetry, the principal-agent relationship between the central government and the local government may generate incentive variation and agency variation, which will lead to an adverse selection and moral hazard [43]. Therefore, the central government, as the main party exercising the ownership of natural resources in sea areas, has the obligation and responsibility of formulating and implementing various policies to supervise and constrain local governments to avoid low-quality right confirmation with measures of internal inspection and resources asset audits, etc. in a top-down way to make sure local governments perform high-quality right confirmation.

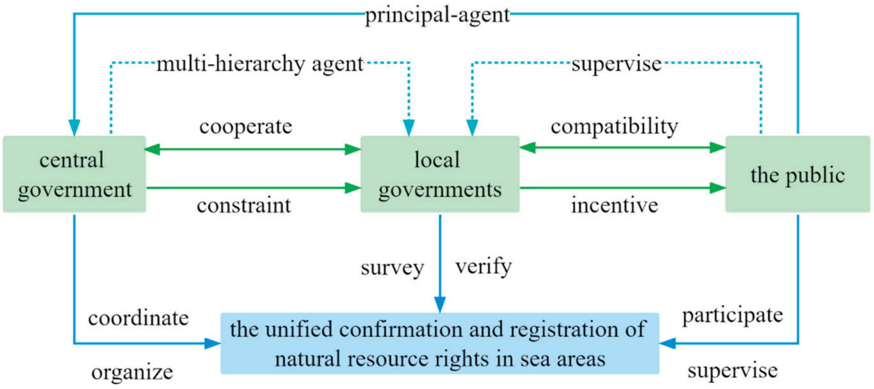


Figure 1. Stakeholder relationship and its interaction mechanism on the UCRNRSA.

2.2. The Interaction Mechanism between the Central Government and the Public Based on the Principal-Agent Relationship

The Law of the People's Republic of China on the Administration of the Use of Sea Areas clearly stipulates that sea areas belong to the state and that the exercise of power in sea areas is divided into direct exercise and agency exercise, which is determined based on the resources list of hierarchical agency of the central government and local governments in holding ownership [28]. The public is the owner of the rights and interests of natural resources. If the central government entrusts local governments to hold ownership, the agent of ownership is registered as the local people's government [26]. The central government will have an impact on URCRNRSA by encouraging the public to participate in the system (Figure 1). In order to improve participating public awareness, the central government can better publicize the property rights system of natural resources by publicly releasing the list and standards of natural resources in sea areas. Then, the central government encourages the public to participate in the supervision of the status of resource right confirmation and guides the public to participate in the marketization of natural resource assets in sea areas. Thereby, the property rights system for natural resources in sea areas will be strengthened. Furthermore, public participation can reduce the cost for the central government to obtain information about the rights registration of local government. The public can be able to obtain information on the current situation of natural resources in local sea areas in real-time. When the public finds that local governments have conducted low-quality practices in the process of URCRNRSA, for example, incomplete right confirmation results, inadequate registration steps, or others, they can put pressure on local governments by way of complaints and petitions as well as report the problems to the central government through public information platforms. The local governments, in order to gain public trust and circumvent the punishment imposed by the central government, prefer to adopt a high standard and strict requirement to conduct a high-quality right confirmation, thereby ensuring the quality of the URCRNRSA.

2.3. The Interaction Mechanism between Local Governments and the Public Based on an Incentive-Compatibility Relationship

According to the principle of incentive-compatibility, the interest goal of local governments is consistent with the goal of maximizing social welfare in the long run, which indicates that local governments, as the defenders of public social interests, must improve the incentive mechanism in the process of the URCRNRSA (Figure 1). In this process, local governments should make the public aware that the interest goal of the URCRNRSA is closely related to the public's own long-term interests and also aware that the public's interests are consistent with the overall welfare of society. In this way, the sense of identity of the public and its enthusiasm are continuously improved to participate in the URCRNRSA. However, at present, due to information asymmetry, low property rights awareness, and high participation costs, the public has insufficient enthusiasm for constructing the URCRNRSA. Compared with other stakeholders, the public is a "vulnerable group". To ensure the interests of the public, the local government should establish an information interaction mechanism between the local government and the public [41]. However, under the assumption that the local government is an economic entity rather than a moral agent, as a self-interested subject, the local government may tend toward excessive expansion of control power, which makes it difficult to effectively contain the opportunism in the process of maximizing the local government's interests. Therefore, for an incentive to be compatible, it is necessary to establish an effective supervision mechanism to expose and correct the behavior that deviates from the public interest [42].

2.4. Evolutionary Game Model Assumptions

Based on the theoretical analysis above, in this study, an analytical framework of the relationship among the central government, local governments, and the public is established for exploring the path of high-quality URCRNRSA. Among them, the central government is the leader, local governments carry out the step-by-step implementation, and the public participates extensively. The central government, local governments, and the public are denoted as X, Y, and Z, based on the premise that they are all bounded rational individuals and have a certain learning ability and behavioral choice right. In addition to the existing pilot scheme procedure of the URCRNRSA, the strategy set of the central government is {auditing, no auditing}, which refers to the key role of the resource asset audit system in constructing the property rights system. Auditing refers to the audit work carried out by the central government to guarantee the quality of resource right confirmation effectively and to clarify the current status of resource property rights. The strategy set of local governments, which are the main party responsible for confirming resource rights, is {high-quality right confirming, low-quality right confirming}. High-quality right confirmation needs the following information: ① information provided with the registration information integration platform; ② natural resources registration information; ③ natural resources record or archive information; ④ information generated by administrative approval; ⑤ information on laws and regulations, government orders, planning, and court decisions; and ⑥ information received by government departments through open registration [44]. The public is the beneficiary of resource right confirmation, and its strategy set is {participating, nonparticipating}. Public participation refers to the direct or indirect participation of stakeholders in the processing of resource right confirmation and public resource affairs [45]. The number of the three types of game groups is considered to be relatively stable and standardized to 1. At time t, the probability that the central government group chooses to audit is $x(t)$, the probability that the local government group chooses to adopt high-quality right confirmation is $y(t)$, and the probability that the public group chooses to adopt participation is $z(t)$.

Based on the scheme of URCRNRSA and the actual situation of the natural resource audit system, the following model assumptions were made:

Hypothesis 1: The central government is a "neutral sector" with the goal of maximizing social welfare and is not captured by any interest group. For the central government, the fixed income from the right confirmation is p_1, and the cost of the right confirmation is c_1. The cost increment of the audit strategy selected by the central government, for example, from hiring external experts for collaboration and standardizing the audit process, is denoted as Δc_1. The public's choice of participation strategy can reduce the right confirmation cost of m incurred by the central government. If the central government chooses the audit strategy, the probability of finding low-quality right confirmation by local governments is η_1, and if it chooses the no audit strategy, the probability of finding low-quality right confirmation by local governments is η_2 ($\eta_1 > \eta_2$), and a fine of h is imposed on local governments.

Hypothesis 2: When the central government chooses the audit strategy, there is a θ probability that the local government authority can be forced to improve the work standards, standardize the right confirmation process, and consequently, the long-term benefits are i brought to the central government from auditing. For local governments, choosing the high-quality right confirmation strategy will bring long-term benefits of r to the central government. When the central government chooses the no audit strategy and local governments choose the low-quality right confirmation strategy, there is a μ probability that the central government will lose its long-term credibility of j.

Hypothesis 3: The standard and requirement of right registration are relatively fixed in a certain period of time, and the cost is certain under the existing technical conditions. The acquisition method and price of the right-to-use sea areas are relatively fixed according to different levels of sea areas. Therefore, we assume that the benefits and costs of the right confirmation are relatively fixed. For local governments, the fixed benefits from right confirmation is p_2, and the fixed cost incurred by the right confirmation is c_2. When local governments choose the high-quality right confirmation strategy, there will be a β probability to bring long-term benefits of d through improving the efficiency of resource market allocation and promoting the fair distribution of resources. At the same time, this strategy choice will also generate an additional right confirmation cost of Δc_2, mainly used for the additional manpower and material resources in order to strengthen the standard and normative basis and unify the basic data. At this time, local governments will have ξ probability of providing incentives to the public for choosing the participation strategy, and the incentive implementation reward to the public will be b. The public's choice of participation strategy may reduce the cost of l of right confirmation incurred by local governments.

Hypothesis 4: When local governments choose the low-quality right confirmation strategy, the probability of rent-seeking behaviors will be δ, and its benefits will be q. At this time, there is a φ probability of damaging the rights and interests of all the resources owned by the whole people, which causes a long-term loss of e in the efficiency of the market-based allocation of resources. When the central government audits, there will be an α_1 probability for the public to find that local governments have carried out low-quality right confirmation if the public chooses the participation strategy. When the central government does not audit, there will be an α_2 probability for the public to find that local governments have carried out low-quality right confirmation if the public chooses the participation strategy, where $\alpha_1 > \alpha_2$. At this time, local governments will give negative externality compensation of n to the public.

Hypothesis 5: For the public, the fixed benefit from the right confirmation is p_3. When local governments perform low-quality URCRNRSA, i.e., a mere formality that causes the rights and interests of all people not to be implemented, the public can adopt the nonparticipation strategy, that is, tolerating the non-implementation of marine resource rights and interests or hoping that the government will take the initiative to improve such implementation. The public can also adopt the participation strategy; that is, the public can protect their legitimate rights and interests through cooperation, reporting, petitioning, etc., and at this time, it will generate participating cost of c_3.

Hypothesis 6: When the public chooses the participation strategy, there is a ξ probability of receiving an incentive of b from local governments. The long-term benefits are v to the public on the condition that local governments carry out high-quality URCRNRSA. When local governments perform low-quality URCRNRSA, the public loss is a_1 on the condition that the central government audits, while on the condition that the central government does not audit, the public loss is a_2, where $a_2 > a_1$.

All the variable definitions are shown in Table 1.

Table 1. Variable definitions.

Definition	Symbol	Definition	Symbol
Central government	X	The long-term benefits from high-quality confirming rights of local governments	d
Local government	Y	The probability of long-term benefits from high-quality confirming rights of local governments	β
The public	Z	The reduced cost of confirming rights by local governments due to the public's participation strategy	l
The fixed income from confirming the rights of the central government	p_1	The probability of local governments providing incentives to the public for choosing the participation strategy	ξ
The fixed cost of confirming the rights of the central government	c_2	The reward of local governments to the public for choosing the participation strategy	b
The reduced cost of confirming rights by the central government due to the public's participation strategy	m	The probability of rent-seeking behaviors of local governments in confirming rights	δ
The increased cost auditing of the central government	Δc_1	The benefits of rent-seeking behaviors of local governments in confirming rights	q
The long-term benefits of the central government from high-quality confirming rights	r	The long-term loss of local governments with low-quality confirming rights	e
The probability of finding local governments low-quality confirming rights by the central government with the audit strategy	η_1	The probability of long-term loss of local governments with low-quality confirming rights	φ
The probability of finding local governments low-quality confirming rights by the central government without an audit strategy	η_2	The probability of the public finding low-quality confirming rights with choosing the participation strategy	α_1
A fine for local governments' low quality confirming rights by the central government	h	The probability of the public finding low-quality confirming rights without choosing the participation strategy	α_2
The long-term benefits of the central government from the audit strategy	i	The negative externality compensation for the public from local governments	n
The probability of long-term benefits for the central government from the audit strategy	θ	The fixed income from confirming the rights of the public	p_3
The benefit loss of the central government without audit strategy under the condition of low-quality confirming rights	j	The cost of the public for choosing the participation strategy of confirming rights	c_1
The probability of benefit loss of the central government without audit strategy under the condition of low-quality confirming rights	μ	The long-term benefits for the public from high-quality confirming rights	v
The fixed income of local governments from confirming rights	p_2	The benefit loss of the public from low-quality confirming rights with central government audit strategy	a_1
The fixed cost of local governments from confirming rights	c_2	The benefit loss of the public from low-quality confirming rights without a central government audit strategy	a_2
The extra cost of local governments from high-quality confirming rights	Δc_2		

Based on the descriptions and research hypotheses on the central government, local governments, and the public with regard to the URCRNRSA above, the payment matrix of their respective strategic behavior is shown in Table 2.

Table 2. Payoff matrix of tripartite evolutionary game.

Strategy	The Central Government	The Local Government	The Pubilc
(auditing, high-quality confirming rights, participating)	$p_1 - c_1 - \Delta c_1 + \theta i + m + r$	$p_2 - c_2 - \Delta c_2 + \beta d + l - \xi b$	$p_3 - c_3 + \xi b + v$
(auditing, high-quality confirming rights, nonparticipating)	$p_1 - c_1 - \Delta c_1 + \theta i + r$	$p_2 - c_2 - \Delta c_2 + \beta d - \xi b$	$p_3 + v$
(auditing, low-quality confirming rights, participating)	$p_1 - c_1 - \Delta c_1 + \theta i + m + \eta_1 h$	$p_2 - c_2 + \delta q - \varphi e - \eta_1 h - \alpha_1 n$	$p_3 - c_3 + \alpha_1 n - a_1$
(auditing, low-quality confirming rights, nonparticipating)	$p_1 - c_1 - \Delta c_1 + \theta i + \eta_1 h$	$p_2 - c_2 + \delta q - \varphi e - \eta_1 h$	$p_3 - a_1$
(no auditing, high-quality confirming rights, participating)	$p_1 - c_1 - \mu j + r$	$p_2 - c_2 - \Delta c_2 + \beta d + l - \xi b$	$p_3 - c_3 + \xi b + v$
(no auditing, high-quality confirming rights, nonparticipating)	$p_1 - c_1 - \mu j + r$	$p_2 - c_2 - \Delta c_2 + \beta d - \xi b$	$p_3 + v$
(no auditing, low-quality confirming rights, participating)	$p_1 - c_1 - \mu j + \eta_2 h$	$p_2 - c_2 + \delta q - \varphi e - \eta_2 h - \alpha_1 n$	$p_3 - c_3 + \alpha_2 n - a_2$
(no auditing, low-quality confirming rights, nonparticipating)	$p_1 - c_1 - \mu j + \eta_2 h$	$p_2 - c_2 + \delta q - \varphi e - \eta_2 h$	$p_3 - a_2$

3. Model Construction and Stability Point Analysis

3.1. Construction of Strategy Selection Models for the Tripartite

In the process of the URCRNRSA, it is necessary to comprehensively consider the main factors that affect the payment function of each party and analyze how the changes of different factors affect the choice of the game parties in order to achieve the optimal strategy combination that is most conducive to the overall system.

In the initial stage, it is assumed that the probability for the central government to audit is x ($0 \leq x \leq 1$) and that the probability of choosing not to audit is 1-x. The probability is y ($0 \leq y \leq 1$) for local governments choosing to carry out high-quality rights confirmation, and the probability is 1-y to perform low-quality right confirmation. The probability of public participation is z ($0 \leq z \leq 1$), and the probability of nonparticipation is 1-z.

1. Analysis of the evolutionary stability strategy of the central government.

The expected utilities of the central government auditing and the central government not auditing are as follows:

$$E_x = yr + zm + (1-y)\eta_1 h + (p_1 - c_1 - \Delta c_1 + \theta i) \quad (1)$$

$$E_{1-x} = yr + (1-y)\eta_2 h + (p_1 - c_1 - \mu j) \quad (2)$$

The average payment of the central government when making strategic choices is as follows:

$$E_1 = yr + xzm + x(1-y)\eta_1 h + x(\theta i - \Delta c_1) + (1-x)(1-y)\eta_2 h - (1-x)\mu j + (p_1 - c_1) \quad (3)$$

Then, the replicator dynamics equation for the strategy selection of the central government is as follows:

$$\frac{dx}{dt} = x(1-x)[(1-y)(\eta_1 h - \eta_2 h) + zm + (\theta i + \mu j - \Delta c_1)] \quad (4)$$

$$0 \leq z = \frac{\eta_1 h - \eta_2 h}{m} y + \frac{\Delta c_1 + \eta_2 h - \theta i - \mu j - \eta_1 h}{m} \leq 1 \quad (5)$$

$$0 \leq z \neq \frac{\eta_1 h - \eta_2 h}{m} y + \frac{\Delta c_1 + \eta_2 h - \theta i - \mu j - \eta_1 h}{m} \leq 1 \quad (6)$$

When Formula (5) is true, the value of Formula (4) is always 0. Regardless of the value of x, the strategy selection process of the central government is in a stable state.

When Formula (6) is true, the value of Formula (4) is 0. When x = 0 or x = 1, the strategy selection process of the central government is in a stable state.

The partial derivative of the replicator dynamics equation is as follows:

$$\frac{d\dot{x}}{dt} = (1-2x)[(1-y)(\eta_1 h - \eta_2 h) + zm + (\theta i + \mu j - \Delta c_1)] \quad (7)$$

At this time, the discussion of the stable equilibrium is carried out under different conditions as follows.

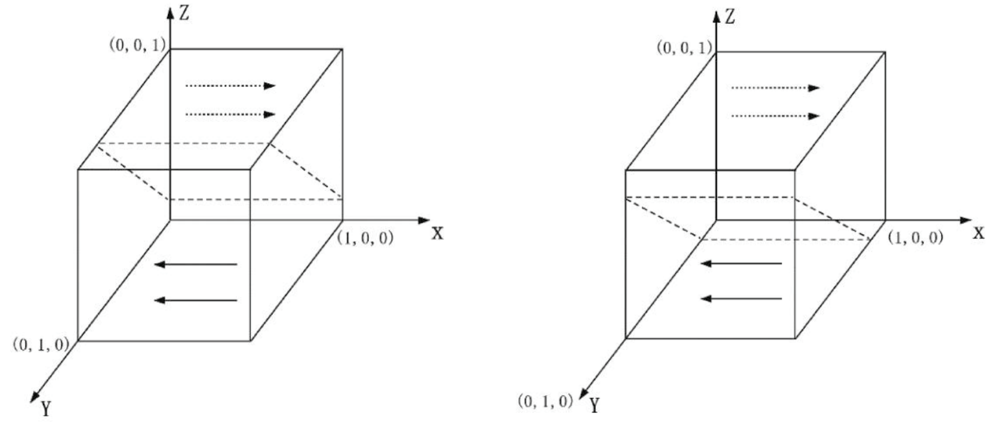
$$0 \leq \frac{\eta_1 h - \eta_2 h}{m} y + \frac{\Delta c_1 + \eta_2 h - \theta i - \mu j - \eta_1 h}{m} < z \leq 1 \tag{8}$$

$$0 \leq z < \frac{\eta_1 h - \eta_2 h}{m} y + \frac{\Delta c_1 + \eta_2 h - \theta i - \mu j - \eta_1 h}{m} \leq 1 \tag{9}$$

When Formula (8) is true, Formula (7) is greater than 0 at $x = 0$, and Formula (7) is less than 0 at $x = 1$, $x = 1$ is the evolutionary stable point. That is, the central government chooses the auditing strategy.

When Formula (9) is true, Formula (7) is less than 0 at $x = 0$, and Formula (7) is greater than 0 at $x = 1$, $x = 0$ is the evolutionary stable point. That is, the central government does choose the no auditing strategy.

The evolutionary stable strategy (ESS) of the central government can be obtained by solving the replicator dynamics equation of the central government (Figure 2).



(**a**). $0 < \frac{\Delta c_1 + \eta_2 h - \theta i - \mu j - \eta_1 h}{m} < 1$ (**b**). $-1 < \frac{\Delta c_1 + \eta_2 h - \theta i - \mu j - \eta_1 h}{m} < 0$

Figure 2. Evolution phase diagram of central government strategy selection under different conditions.

2. Analysis of the evolutionary stability strategy of local governments.

The expected utilities of high-quality right confirmation and low-quality right confirmation by local governments are as follows:

$$E_y = zl + (p_2 + \beta d - c_2 - \Delta c_2 - \xi b) \tag{10}$$

$$E_{1-y} = -x\eta_1 h - (1-x)\eta_2 h - z\alpha_2 n + xz(\alpha_2 n - \alpha_1 n) + (p_2 + \delta q - c_2 - \varphi e) \tag{11}$$

The average payment of local governments when making strategic choices is as follows:

$$\begin{gathered} E_2 = yzl + y(\beta d - \Delta c_2 - \xi b) - x(1-y)\eta_1 h - (1-x)(1-y)\eta_2 h - (1-y)z\alpha_2 n \\ + x(1-y)z(\alpha_2 n - \alpha_1 n) + (1-y)(\delta q - \varphi e) + (p_2 - c_2) \end{gathered} \tag{12}$$

Then, the replicator dynamics equation for the strategy selection of local governments is as follows:

$$\frac{dy}{dt} = y(1-y)[x(\eta_1 h - \eta_2 h) + z(l + \alpha_2 n) + xz(\alpha_1 n - \alpha_2 n) + (\beta d + \varphi e + \eta_2 h - \Delta c_2 - \xi b - \delta q)] \tag{13}$$

$$0 \leq z = \frac{x(\eta_2 h - \eta_1 h) - (\beta d + \varphi e + \eta_2 h - \Delta c_2 - \xi b - \delta q)}{x(\alpha_1 n - \alpha_2 n) + \alpha_2 n + l} \leq 1 \tag{14}$$

$$0 \leq z \neq \frac{x(\eta_2 h - \eta_1 h) - (\beta d + \varphi e + \eta_2 h - \Delta c_2 - \xi b - \delta q)}{x(\alpha_1 n - \alpha_2 n) + \alpha_2 n + l} \leq 1 \tag{15}$$

When Formula (14) is true, the value of Formula (13) is always 0. Regardless of the value of y, the strategy selection process of local governments is in a stable state.

When Formula (15) is true, the value of Formula (13) is 0. When $y = 0$ or $y = 1$, the strategy selection process of local governments is in a stable state.

The partial derivative of the replicator dynamics equation is as follows:

$$\frac{d\dot{y}}{dt} = (1-2y)[x(\eta_1 h - \eta_2 h) + z(l + \alpha_2 n) + xz(\alpha_1 n - \alpha_2 n) + (\beta d + \varphi e + \eta_2 h - \Delta c_2 - \xi b - \delta q)] \tag{16}$$

At this time, the discussion of the stable equilibrium is carried out under different conditions as follows.

$$0 \le \frac{x(\eta_2 h - \eta_1 h) - (\beta d + \varphi e + \eta_2 h - \Delta c_2 - \xi b - \delta q)}{x(\alpha_1 n - \alpha_2 n) + \alpha_2 n + l} < z \le 1 \tag{17}$$

$$0 \le z < \frac{x(\eta_2 h - \eta_1 h) - (\beta d + \varphi e + \eta_2 h - \Delta c_2 - \xi b - \delta q)}{x(\alpha_1 n - \alpha_2 n) + \alpha_2 n + l} \le 1 \tag{18}$$

When Formula (17) is true, Formula (16) is greater than 0 at $y = 0$, and Formula (16) is less than 0 at $y = 1$, $y = 1$ is the evolutionary stable point. That is, the local governments choose the strategy of high-quality right confirmation.

When Formula (18) is true, Formula (16) is less than 0 at $y = 0$, and Formula (16) is greater than 0 at $y = 1$, $y = 0$ is the evolutionary stable point. That is, the local governments choose the strategy of low-quality right confirmation.

The ESS of local governments can be obtained by solving the local government replicator dynamics equation (Figure 3).

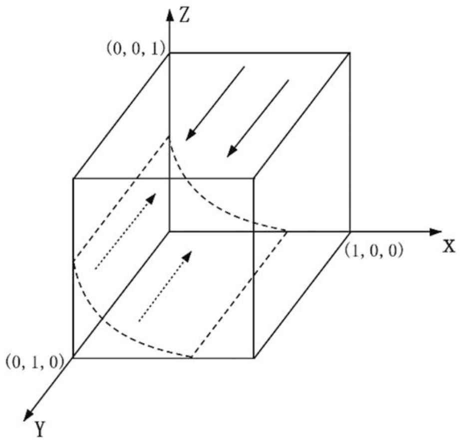


Figure 3. Evolution phase diagram of local government strategy selection.

3. Analysis of the evolutionary stability strategy of the public

The expected utilities of public participation and public nonparticipation are as follows:

$$E_z = y(\xi b + v) + x(1-y)\alpha_1 n + (1-x)(1-y)\alpha_2 n - x(1-y)a_1 - (1-x)(1-y)a_2 + (p_3 - c_3) \tag{19}$$

$$E_{1-z} = yv - x(1-y)a_1 - (1-x)(1-y)a_2 + p_3 \tag{20}$$

The average payment of the public when choosing the strategy of participation or nonparticipation is as follows:

$$\begin{aligned} E_3 = {} & yz\xi b + yv + x(1-y)z\alpha_1 n + (1-x)(1-y)z\alpha_2 n - x(1-y)za_1 \\ & -(1-x)(1-y)za_2 - x(1-y)(1-z)a_1 \\ & -(1-x)(1-y)(1-z)a_2 + p_3 \end{aligned} \tag{21}$$

The replicator dynamics equation for the strategy selection of the public is as follows:

$$\frac{dz}{dt} = z(1-z)[y(\xi b - \alpha_2 n) + x(\alpha_1 n - \alpha_2 n) + xy(\alpha_1 n - \alpha_2 n) + (\alpha_2 n - c_3)] \tag{22}$$

$$0 \le y = \frac{x(\alpha_2 n - \alpha_1 n) + c_3 - \alpha_2 n}{x(\alpha_2 n - \alpha_1 n) + \xi b - \alpha_2 n} \le 1 \tag{23}$$

$$0 \le y \neq \frac{x(\alpha_2 n - \alpha_1 n) + c_3 - \alpha_2 n}{x(\alpha_2 n - \alpha_1 n) + \xi b - \alpha_2 n} \le 1 \tag{24}$$

When Formula (23) is true, the value of Formula (22) is always 0. Regardless of the value of z, the strategy selection process of the public is in a stable state.

When Formula (24) is true, the value of Formula (22) is 0. When z = 0 or z = 1, the strategy selection process of the public is in a stable state.

The partial derivative of the replicator dynamics equation is as follows:

$$\frac{d\dot{z}}{dt} = (1-2z)[y(\xi b - \alpha_2 n) + x(\alpha_1 n - \alpha_2 n) + xy(\alpha_1 n - \alpha_2 n) + (\alpha_2 n - c_3)] \tag{25}$$

At this time, the discussion of the stable equilibrium is carried out under different conditions as follows.

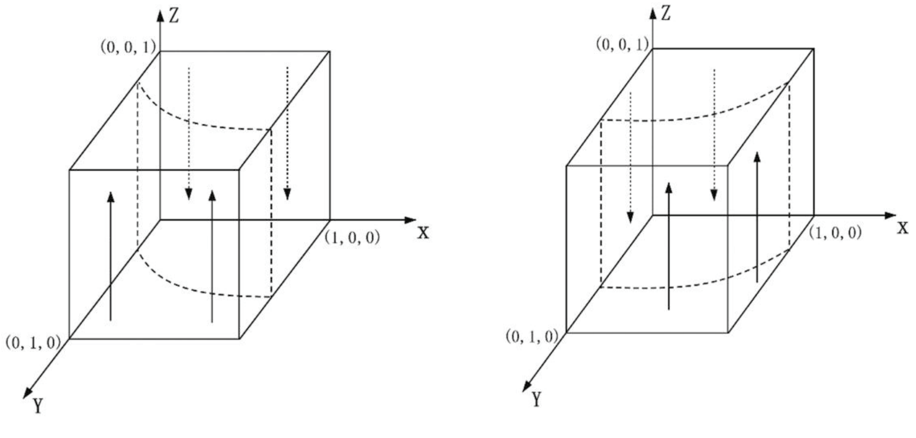
$$0 \le \frac{x(\alpha_2 n - \alpha_1 n) + c_3 - \alpha_2 n}{x(\alpha_2 n - \alpha_1 n) + \xi b - \alpha_2 n} < y \le 1 \tag{26}$$

$$0 \le y < \frac{x(\alpha_2 n - \alpha_1 n) + c_3 - \alpha_2 n}{x(\alpha_2 n - \alpha_1 n) + \xi b - \alpha_2 n} \le 1 \tag{27}$$

When Formula (26) is true, Formula (25) is greater than 0 at z = 0, and Formula (25) is less than 0 at z = 1, z = 1 is the evolutionary stable point. That is, the public chooses the participation strategy.

When Formula (27) is true, Formula (25) is less than 0 at z = 0, and Formula (25) is greater than 0 at z = 1, z = 0 is the evolutionary stable point. That is, the public chooses the nonparticipation strategy.

The ESS of the public can be obtained by solving the public replicator dynamics equation (Figure 4).



(**a**). $\xi b - \alpha_2 n > 0, \xi b - c_3 > 0$ (**b**). $\xi b - \alpha_2 n < 0, \xi b - c_3 < 0$

Figure 4. Evolution phase diagram of the public strategy selection under different conditions.

3.2. Stability Point Analysis

According to the Malthusian equation, the three−dimensional dynamic system (J) can be obtained by calculating the replicator dynamics equation of the central government, local governments, and the public.

The analysis results of the three−dimensional dynamic system (J) show that there are eight pure strategy equilibrium points and one mixed strategy equilibrium point adopted by the tripartite in the system (J), theoretically [46]. In an asymmetric game, the evolutionary game equilibrium E is an evolutionary stable equilibrium and must be a strict Nash equilibrium. Moreover, a strict Nash equilibrium is a pure strategy equilibrium [47]. That is, the mixed strategy equilibrium in an asymmetric game must not be an evolutionary stable equilibrium [48]. Therefore, this paper discusses only the eight stable points of pure strategy equilibrium of the tripartite evolutionary game.

Then this paper tries to further solve the stable equilibrium point of the system (J) evolution. When all the eigenvalues λ of the Jacobian matrix have a negative real part, the equilibrium point is an asymptotically stable point according to the Lyapunov stability theory [49]. If not all eigenvalues λ are <0, it is necessary to further determine whether the equilibrium point is a saddle point.

To simplify the calculation process, make $\eta_1 h - \eta_2 h = A$, $\theta i - \mu j - \Delta c_1 = B$, $\alpha_2 n + l = C$, $\alpha_1 n - \alpha_2 n = D$, $\beta d + \varphi e + \eta_2 h - \xi b - \delta q - \Delta c_2 = E$, $\xi b - \alpha_2 n = F$, $\alpha_2 n - c_3 = G$.

The system (J) Jacobian matrix is as follows:

$$\begin{bmatrix} (1-2\mathrm{x})[(1-y)A+zm+B] & -x(1-x)A & x(1-x)m \\ y(1-y)(A+zD) & (1-2y)(xA+zC+xzD+E) & y(1-y)(c+xD) \\ z(1-z)(D-yD) & z(1-z)(F-xD) & (1-2z)(yF+xD-xyD+G) \end{bmatrix} \tag{28}$$

Based on the matrix above, the eight pure strategy stability points of the system (J) and their eigenvalues can be obtained (Table 3).

Table 3. System J equilibrium points and its eigenvalues.

Equilibrium Point	Eigenvalues			Condition of Asymptotically Stable Points
	λ_1	λ_2	λ_3	
E_1(0,0,0)	A + B	E	G	A + B < 0, E < 0, G < 0
E_2(0,0,1)	A + B + m	C + E	− G	A + B + m < 0, C + E < 0, − G < 0
E_3(0,1,0)	B	− E	F + G	B < 0, − E < 0, F + G < 0
E_4(1,0,0)	− B	A + E	D + G	− B < 0, A + E < 0,D + G < 0
E_5(1,0,1)	− A − B − m	A + C + D + E	− D − G	− A − B − m < 0, A + C + D + E < 0, − D − G < 0
E_6(0,1,1)	B + m	− C − E	− F − G	B + m < 0, − C − E < 0, − F − G < 0
E_7(1,1,0)	− B	− A − E	F + G	− B < 0, − A − E < 0, F + G < 0
E_8(1,1,1)	− B − m	− A − C − D − E	− F − G	− B − m < 0, − A − C − D − E < 0, − F − G < 0

Table 3 indicates that the central government will choose the strategy of audit if the sum of the long-term benefits of central government auditing and the long-term loss of not auditing is greater than the audit cost. Otherwise, the central government will not choose the strategy of an audit. For local governments, according to the cooperation-constraint relationship, under the condition of relatively fixed benefits and costs of right confirmation, the quality of right confirmation is dependent on the intensity of penalties imposed on local governments for low-quality right confirmation by the central government. If the penalties are severe, local governments will choose to carry out a high-quality right confirmation strategy. While the penalties are lenient, they will choose the low-quality right confirmation strategy. As to the public, they will consider the incentive intensity of local governments and their participation cost. Moreover, they will also consider the externality compensation obtained when they find low-quality right confirmation. If both the incentive intensity and the externality compensation are too low and the participation cost is high, the public will choose the strategy of nonparticipation; otherwise, they will select the strategy of participation.

4. Scenario Simulation and Parameter Analysis

The stability points and conditions are obtained for the evolutionary game of the central government, local governments, and the public according to the solution of the equilibrium point of the evolutionary game model and the analysis of the asymptotic stability condition of the equilibrium point above. On this basis, the principle is clarified for simulating tripartite strategy selection; that is, the model variables and parameter assignments must satisfy economic assumptions and empirical judgments, i.e., the principle of changing the value of specific assignments without changing the simulation results [50].

In order to explore the most effective strategy profile to achieve high-quality right confirmation, scenario simulating is conducted on the evolution path of stable points. Then the evolutionary stability path map is drawn by analyzing the evolution conditions of tripartite and the value range of the parameters. The sensitivity of parameters is analyzed to explore the factors influencing the selection of the evolutionary stability path. Under the initial condition, assume probabilities of auditing by the central government $x = 0.5$, high-quality right confirmation by local governments $y = 0.5$, and participation by the public $z = 0.5$.

4.1. Scenario 1: The Central Government does Not Audit, Local Governments Carry out High-Quality Right Confirmation, and the Public does Not Participate

The stable point of scenario 1 is E3 (0, 1, 0), which needs to satisfy three inequality conditions to evolve into an ESS. In this study, MATLAB 2016a software is used to numerically simulate the process of the tripartite strategy adjusting and evolving. The specific evolutionary paths of parameter assignment are shown in Figures 5 and 6. In Figure 5, the abscissa represents the passage of time, the ordinate represents the probability of each part strategy selection, and the curve represents the evolutionary process of each part behavior. Figure 5 indicates that over time, local governments take the lead to reach the equilibrium point of evolution and choose high-quality right confirmation. Then, the central government reaches the equilibrium point at a faster speed and chooses to audit, while the public needs a longer evolutionary process to reach the equilibrium point and chooses not to participate. The tripartite strategy will evolve to equilibrium when $t = 2$. Figure 6 shows that the evolution process of probability for the tripartite to choose a strategy moves from the initial point (0.5, 0.5, 0.5) to stable point E3 (0, 1, 0).

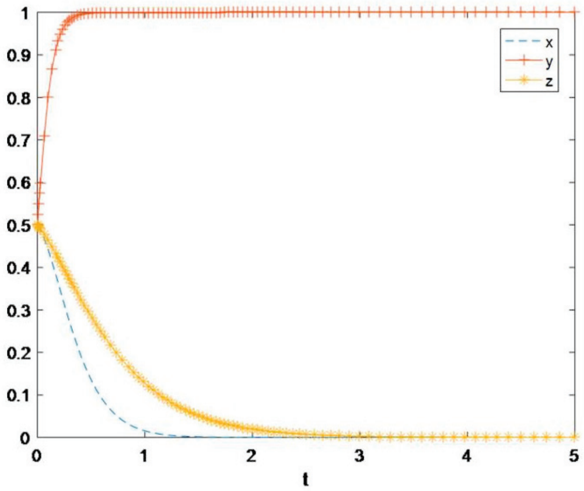


Figure 5. Two-dimensional diagram of evolutionary path at stable point (0, 1, 0).

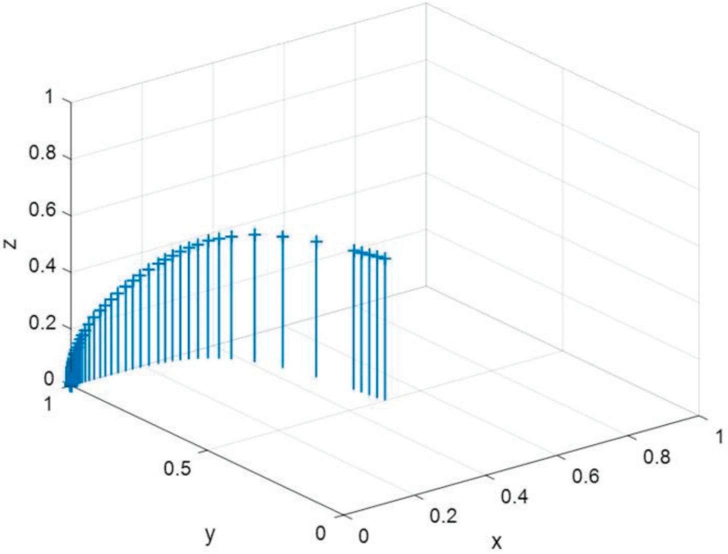


Figure 6. Three-dimensional diagram of evolutionary path at stable point (0, 1, 0).

4.2. Scenario 2: The Central Government does Not Audit, Local Governments Carry out High-Quality right Confirmation, and the Public Participate

The stable point of scenario 2 is E6 (0, 1, 1), which needs to meet the following conditions to evolve into an ESS. The specific evolutionary paths are shown in Figures 7 and 8. Figure 7 indicates that over time, local governments will adjust to the high-quality right confirmation strategy at a very fast speed, and the central government will then select the no audit strategy at a relatively fast speed, while the public will need a longer time to evolve to reach equilibrium and choose nonparticipation. As shown in Figure 7, the tripartite strategy will evolve to equilibrium when $t = 4$. Figure 8 shows that the evolution of the tripartite strategy selection probability moves from the initial point (0.5, 0.5, 0.5) to stable point E6 (0, 1, 1).

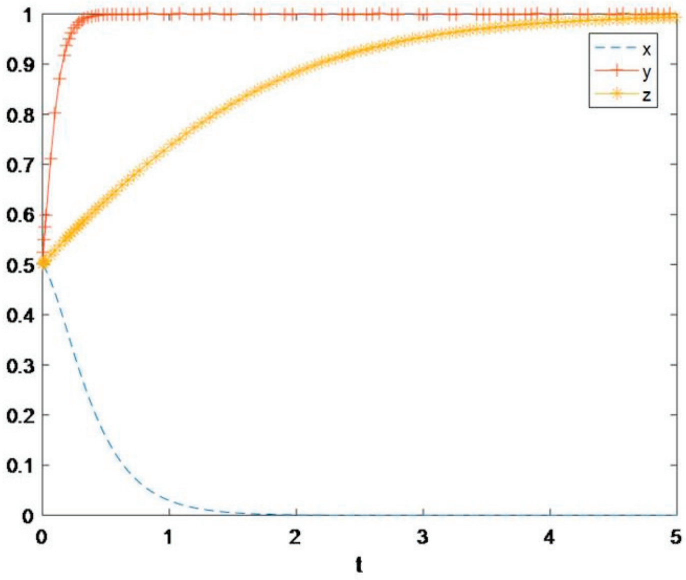


Figure 7. Two-dimensional diagram of evolutionary path at stable point (0, 1, 1).

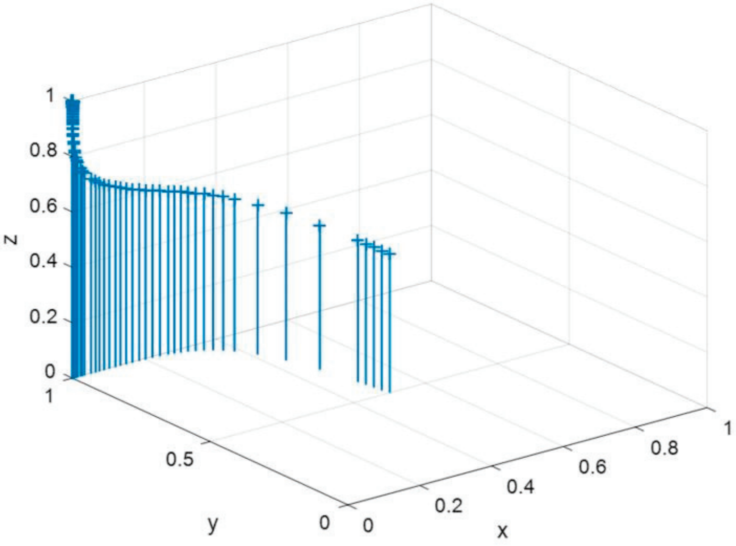


Figure 8. Three-dimensional diagram of evolutionary path at stable point (0, 1, 1).

4.3. Scenario 3: The Central Government Audits, Local Governments Carry out High-Quality Right Confirmation, and the Public does Not Participate

The stable point of scenario 3 is E7 (1, 1, 0), which needs to meet the following conditions to evolve into an ESS. The specific evolutionary paths are shown in Figures 9 and 10. Figure 9 indicates that over time, local governments will adjust to the high-quality right confirmation strategy at a very fast speed. The central government will then select the audit strategy at a faster speed, while the public will need a longer time to choose the nonparticipation strategy to reach equilibrium. As shown in Figure 9, the tripartite strategy will evolve to equilibrium when $t = 4$. Figure 10 shows that the evolution of the tripartite strategy selection probability moves from the initial point (0.5, 0.5, 0.5) to stable point E7 (1, 1, 0).

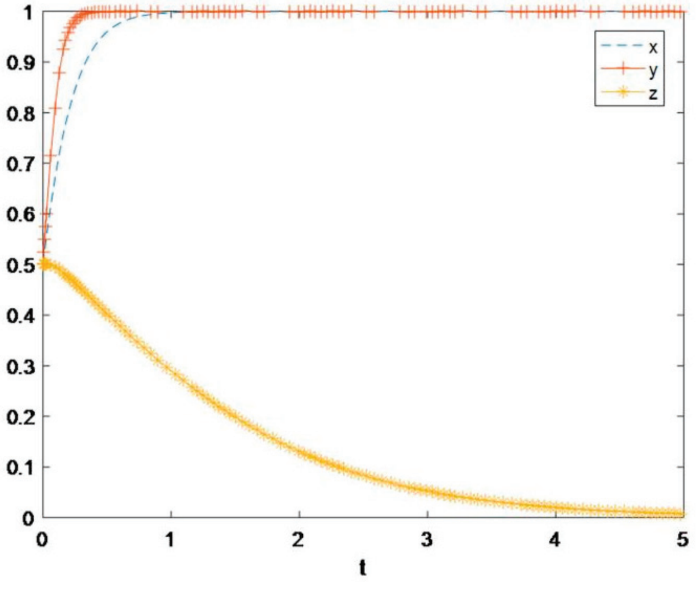


Figure 9. Two-dimensional diagram of evolutionary path at stable point (1, 1, 0).

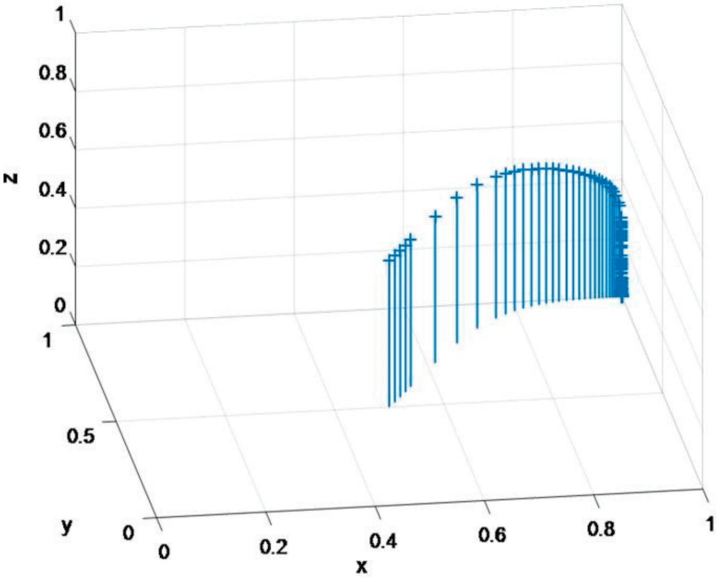


Figure 10. Three-dimensional diagram of evolutionary path at stable point (1, 1, 0).

4.4. Scenario 4: The Central Government Audits, Local Governments Carry out High-Quality Right Confirmation, and the Public Participate

The stable point of scenario 4 is E8 (1, 1, 1), which needs to meet the following conditions to evolve into an ESS. The specific evolutionary paths are shown in Figures 11 and 12. Figure 11 indicates that over time, local governments will adjust to a high-quality right confirmation strategy at a very fast speed. The central government will then select the audit strategy at a relatively fast speed, while the public will need a long time to evolve to reach equilibrium and participate. As shown in Figure 11, the tripartite strategy will evolve to equilibrium when $t = 4$. Figure 12 shows that the evolution of the tripartite strategy selection probability moves from the initial point (0.5, 0.5, 0.5) to stable point E8 (1, 1, 1).

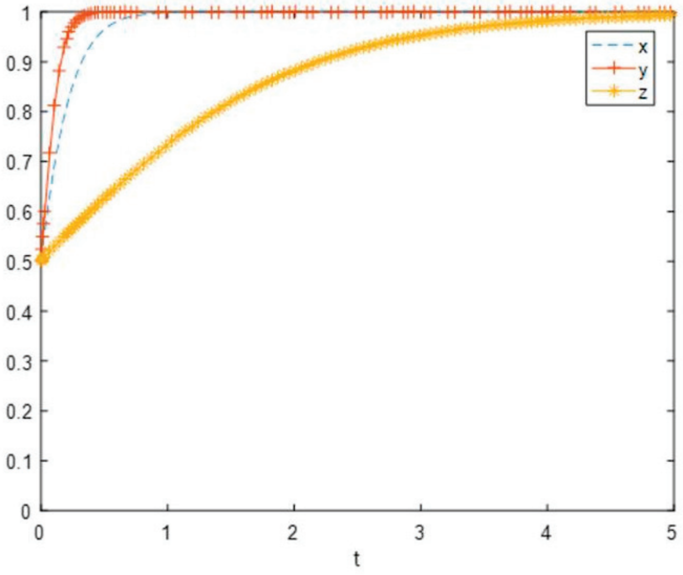


Figure 11. Two-dimensional diagram of evolutionary path at stable point (1, 1, 1).

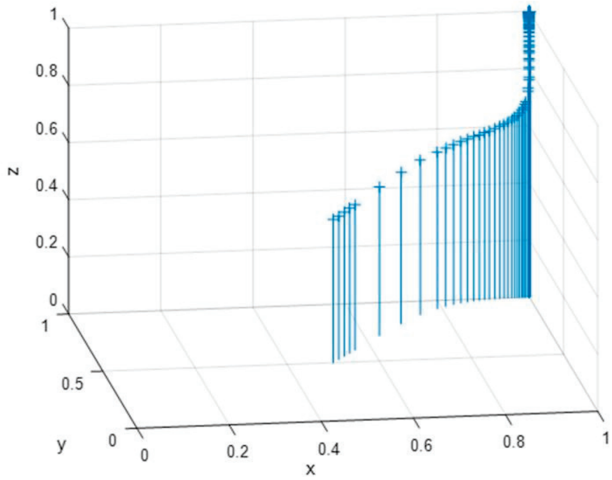
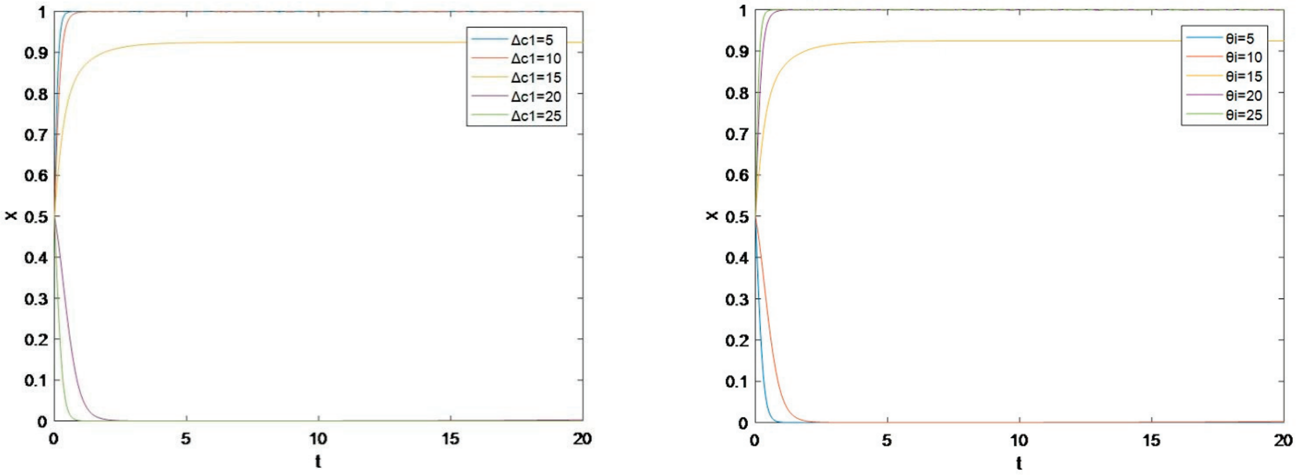


Figure 12. Three-dimensional diagram of evolutionary path at stable point (1, 1, 1).

Above all, the analysis results from all the scenarios revealed that the strategy set of the central government auditing, local government high-quality right confirming, and public participation is the most effective governance system for high-quality URCRNRSA. In different specific practices, the tripartite made different strategy selections, which indicated various effects of policy. In scenario 1, the strict self-restraint mechanism is difficult to realize for local governments. The "soft" constraint with only public participation is not applicable under scenario 2. Moreover, the "hard" constraint with only the central government is not conducive to long-term managing local governments under scenario 3. While in scenario 4, the central government can make good use of audit supervision to constrain the motives and low-quality right confirmation behaviors of local governments, the incentive system of local governments can stimulate public participation in right confirmation, and public participation can reduce the cost of right confirmation incurred by the central and local governments. That is, in this scenario, it would be more realistic for local governments to choose high-quality right confirmation under the dual institutional constraints of the central government and the public.

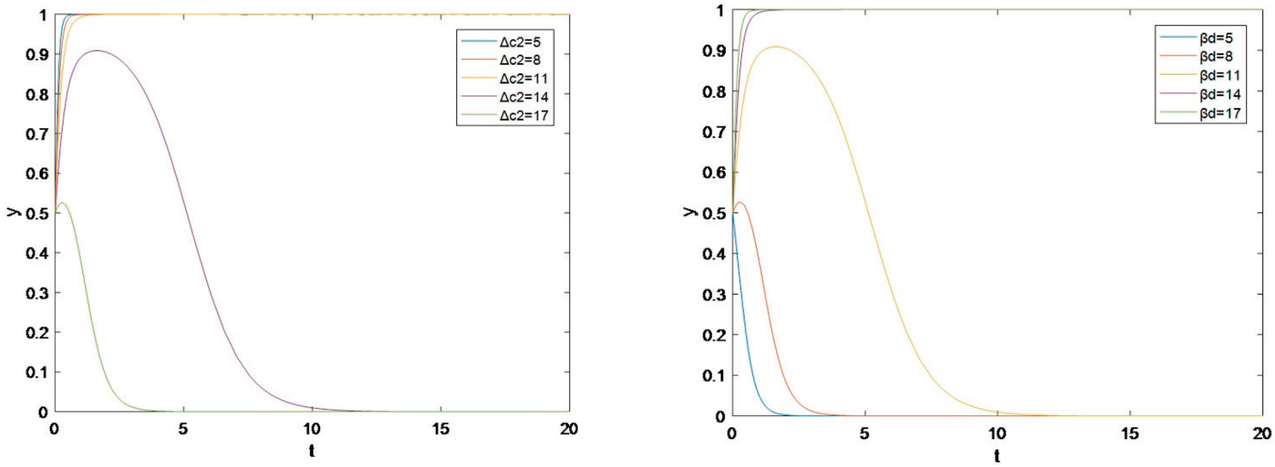
4.5. Parameter Analysis

Nowadays, the practice of local government right confirmation is at the exploratory stage, and there is still a certain gap with the theoretical high-quality right confirmation because there are no clear central government audit procedures and public participation measures in the current pilot program for URCRNRSA in China. Therefore, the influencing factors of high-quality URCRNRSA are explored by conducting the parameter analysis in this study. The initial conditions of stable point E1 (0, 0, 0) are used as the reference, and then the parameters are set to $\eta_1 h = 10$, $\eta_2 h = 5$, $\theta i = 10$, $\mu j = 5$, $\Delta c_1 = 20$, $m = 2$, $\alpha_2 n = 3$, $l = 2$, $\alpha_1 n = 2$, $\beta d = 10$, $\varphi e = 10$, $\delta q = 10$, $\Delta c_2 = 15$, $\xi b = 2$, $c_3 = 3$. The relevant parameters of the benefits and costs of different entities are set separately to further analyze the impact of each parameter change on the model [51]. The general benefits and costs of the tripartite are relatively fixed for a certain period of time. In contrast, the important influencing factors are long-term benefits, additional audit costs, penalty intensity, the additional costs of rights confirmation, incentive levels, compensation levels, etc. Therefore, this study, focusing on the impact of the different parameter changes above on the strategy selection of various entities, tries to explore the influencing factors of the evolutionary stable path of the strategy selection. The stimulating evolutionary stable path of the strategy selection is conducted on the condition of changing the parameters (Figures 13–16).



(**a**) The impact of additional audit costs on central government strategies (**b**) The impact of long-term benefits on central government strategies

Figure 13. The impact of additional audit costs and long-term benefits on central government strategies.

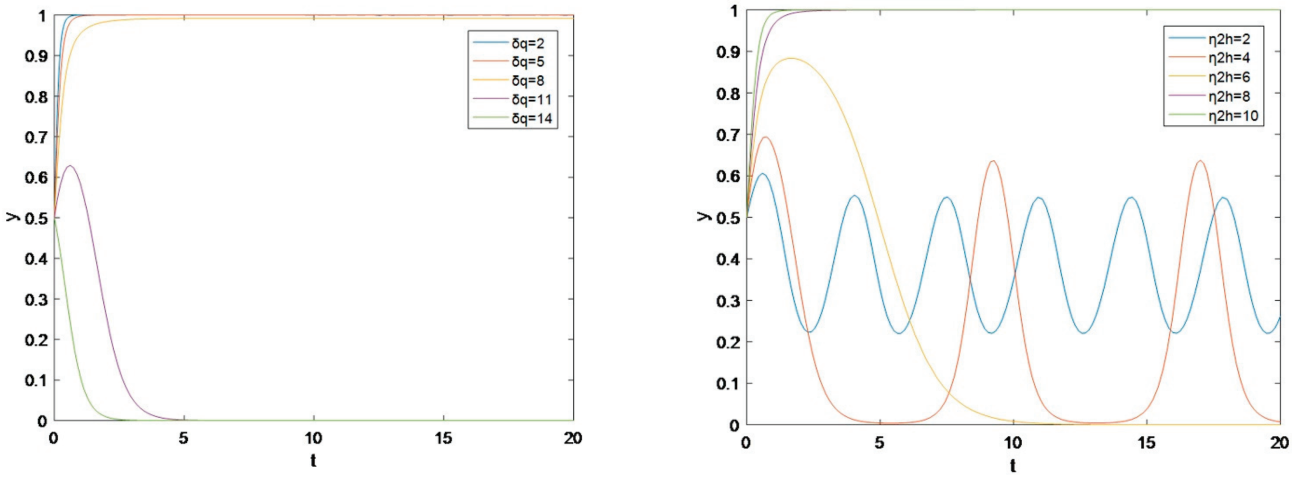


(**a**) The impact of additional confirmation costs on local government's strategies. (**b**) The impact of long-term benefits on local government's strategies.

Figure 14. The impact of additional confirmation costs and long-term benefits on local government's strategies.

Figure 13 shows that both reducing additional audit cost Δc_1 and increasing long-term benefits θi can promote the evolution of the central government in the direction of choosing the audit strategy. When auditing, the central government should consider not only the issues of short-term costs, such as the additional manpower and material resources involved in the URCRNRSA but also the issues of long-term economic and social benefits.

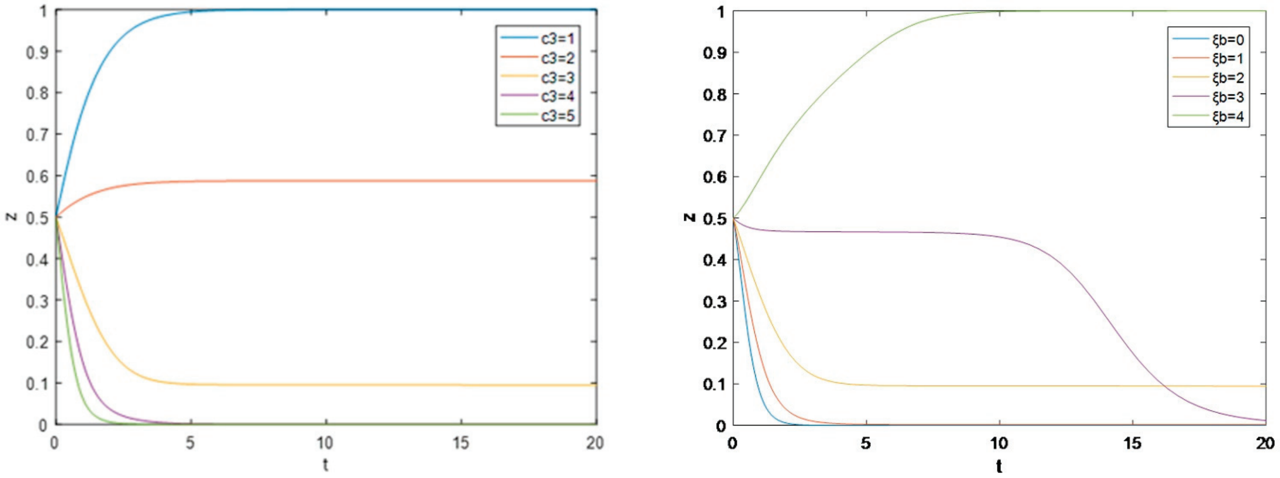
Figures 14 and 15 show that when making strategic selections, local governments will pay attention to the issues of the additional cost of right confirmation Δc_2 and accountability penalty $\eta_2 h$. Both reducing the additional cost of right confirmation and increasing the accountability penalty can promote the evolution of local government's strategic selection to the high-quality right confirmation strategy. In contrast, an appropriate increase in the intensity of accountability and penalty will have a greater impact on the probability of strategic selection. Furthermore, local governments will pay attention to the issues of long-term benefits βd and the benefits of rent-seeking behaviors δq. Both reducing the benefits of rent-seeking behaviors and increasing the long-term benefits will promote the evolution of local government's strategic selection to the high-quality right confirmation strategy.



(**a**) The impact of the benefit from rent-seeking behaviors on local government's strategies.

(**b**) The impact of accountability or punishment on local government's strategies.

Figure 15. The impact of both the benefit from rent-seeking behaviors and accountability or punishment on local government's strategies.



(**a**) The impact of participation cost on the public strategies

(**b**) The impact of incentive benefits on the public strategies

Figure 16. The impact of participation cost and incentive benefits on the public strategies.

Figure 16 shows that both the relatively high incentive benefits and relatively low participation costs can promote the evolution of the public to choose the participation strategy. When choosing the strategy, the public will consider the level of net benefit from the strategy itself. The public should realize that they will not only be benefited from the URCRNRSA itself but also obtain the incentive benefits from local governments. The government at all levels can reduce the information asymmetry between the public and the government to reduce the cost of public participation by strengthening system construction so as to promote public participation more effectively.

5. Conclusions and Policy Recommendations

5.1. Conclusions

In the present study, auditing by the central government and participation by the public were innovatively incorporated into the analytical framework for the URCRNRSA. The learning behavior and strategy adjustment mechanism of the tripartite in the long-term game process was analyzed by the established "central government-local governments-the public" tripartite evolutionary game model of the URCRNRSA. Scenario simulations were conducted under conditions of different costs and benefits with different parameters. The main conclusions of the study were as follows:

The tripartite of the central government, local governments, and the public jointly affect the URCRNRSA through cooperation-constraint, principal-agent, and incentive-compatibility relationships. The strategic choices of the tripartite are strongly influenced by their costs and benefits, respectively. The local government's behavior in implementing the URCRNRSA could be impacted by the central government and the public. The most effective and realistic strategy for URCRNRSA should be local government high-quality right confirming with the central government auditing as a hard constraint and public participation as a soft constraint. The key factors that influence the strategy choice of the tripartite are cost, benefit, reward, and punishment. The strategy choice of the central government could be driven to evolve in the direction of choosing the audit strategy if reducing additional audit costs and increasing long-term benefits. The strategy choice of local governments could be promoted to evolve in the direction of choosing the high-quality right confirmation through reducing the additional cost of right confirmation, reducing the benefits of rent-seeking behaviors, appropriately increasing accountability penalties, and increasing long-term benefits. At the same time, the strategy choice of the public could be motivated to evolve in the direction of choosing the participation strategy by higher incentive benefits and lower participation costs.

5.2. Policy Recommendations

Based on the research conclusions above, the following policy recommendations are proposed to achieve the most effective strategy selection:

(1) Improve the central government's resource audit mechanism. The central government should establish a comprehensive system of ex-ante supervision, in-process supervision, and post-accountability auditing and reduce the supervision costs of marine natural resources [52]. Introducing a resource audit system in the process of the URCRNRSA can give full play to the role of auditing, further clarify the value and amount of natural resources in sea areas [53], and lay the foundation for the audit of natural resource assets of outgoing leading cadres.

(2) Stimulate local governments' motivation for high-quality right confirmation and registration. The central government should clarify the standards and procedures of the URCRNRSA and strengthen the supervision and auditing of local governments. Particularly, the central government should strengthen whole process management, such as improving the performance evaluation ratio, refining the evaluation indicators, appropriately increasing the intensity of penalties and accountability, establishing a sound mechanism for taking responsibility so as to reduce the probability of rent-seeking behaviors by local governments [54].

(3) Strengthen public participation and supervision. It is necessary to improve the incentives of public participation in resource asset confirmation and guide the public to correctly realize the important role of rational right confirmation and the development of resource assets in safeguarding the rights and interests of owners. Corresponding public service platforms should be established to disclose information on the URCRNRSA.

The institutional system of URCRNRSA is in the stage of pilot construction, and there is no mature specific case. Limited by the actual data, this study performed a preliminary theoretical exploration of system construction. Therefore, the parameters in this paper could only be set by combining the theoretical analysis of the evolutionary game model and practical experience. In the future, with the continuous development of the URCRNRSA, official statistics could be obtained and with which further empirical analysis could be conducted. In addition, due to the complexity of the distribution of natural sea areas, the right confirmation of a certain sea area maybe involve two or more local governments. This situation has not been considered in this paper, so the game situation should be further analyzed in the future. It is hoped that the results of this study could provide a theoretical basis for future quantitative research, thereby providing a more useful decision-making reference for improving and implementing the system of URCRNRSA in China as well as countries and regions with similar situations.

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Research on Financial Support, Technological Improvement and Marine Economic Development for China's Coastal Regions

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Abstract: Financial support (capital) and technological improvement are the crucial factors in any industry, and they are also the major factors of marine economics. However, the government has supplied a great deal of capital and the marine economy has been deeply explored and researched using advanced technology. The marine industry is still not the mainstay industry in Chinese industry. Considering this, the issues of how to address financial support, technical improvement and marine economics are common foci within the government and society, especially regarding the economic growth of China. It is necessary to develop the marine economy. However, many scholars only pay attention to the aspects of marine financial support, marine technology and marine economic development separately, and no scholars have studied the relationship between the three at present. Therefore, this article establishes a model to conduct empirical tests regarding the relationship between financial support, technological improvement and marine economic development using panel data from 11 coastal regions in China. The results show that financial support has a negative impact on technological improvement, but it has a positive impact on marine economic efficiency. Technological improvement has a positive impact on financial support and marine economic efficiency. However, marine economic efficiency has a negative impact on financial support, and it has a positive impact on technological improvement. Through impulse response analysis, there is a significant correlation between them. This article calculates marine economic efficiency with the SBM-DEA model and analyzes relationships with the BVAR model, which is proposed to improve the development and efficiency of the marine economy. Financial support should be used in the rather important parts of the marine economy so that the marine economy can achieve returns in the short-term and attract more circulating funds to enter the marine economy, which impacts the long-term stable and sustainable growth of the marine economy. Moreover, financial support, financial liberalization, technological research and technological creation in the progress of marine economic construction should focus on effectively using circulating funds, which provides geo-advantages and aids in building a new marine economic ecological circle.

Keywords: financial support; technological improvement; marine economic efficiency; marine biomedicine; SBM-DEA model; BVAR model

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1. Introduction

With the development of economies and the acceleration of globalization, the limited resources on the road are becoming more and more obvious. Two-thirds of Earth's surface are covered by oceans; the global ocean area is about 360 million km^2. Especially, China's ocean area accounts for one third of the global ocean area. Therefore, there is profound significance regarding the development of the ocean economy in terms of exploiting the Chinese marine industry. At present, China's marine economic governance and other policies are emerging from an endless stream, mainly including the development of "blue ocean economy, green marine economy", etc. At the same time, corresponding financial policies are also proposed to support the development of the marine economy. The development experience of China's marine economy has important reference significance to the development of the global marine economy. In the process of marine economic development, there are a series of problems, such as low efficiency of marine scientific and technological innovation, difficulties in the approval of marine-related projects and many financial and technical difficulties. In the high-quality development of China's marine economy, it remains to be verified whether financial support and technical support can play their due role. At present, most scholars in the study of financial support for the development of the marine economy have mainly focused on the study of marine economic policy support for the influence of the marine economy. With the development of the economy, technology and financial aspects are indispensable aspects regarding the marine economy. Xusheng (2021) [1,2]. put forward that financial aspects have an impact on marine economy efficiency in terms of science and technology using the three-stage DEA model for analysis. Qinglong Shao (2020) [3,4] believes that there is a nonlinear impact on marine economic development from scientific and technological innovation on marine pollution From the perspective of input and output, marine pollution is an unexpected output in economic development. Chi-wei Su (2021) [5] analyzed the relationship between China's financial development and marine economic development from the perspective of causal analysis. Marine industry needs to make full use of financial resources, but financial development cannot depend on marine economic growth. The development of the marine economy by technological innovation is not considered. The above studies and the three relations are not integrated and analyzed, and the three relations are not combined with specific examples of comprehensive evaluation and analysis.

The suggestions put forward are often too rigid regarding empirical results, and there is a lack of substantive suggestions combined with actual production activities. In the aspect of addressing marine economic efficiency, only expected output is considered and non-expected output is not considered. Impulse response analysis of the relationship between the three is not carried out.

From the perspective of the relationship between financial support, technological improvement and marine economic development, this paper uses the Bayes vector autoregressive model (BVAR model) to put forward constructive suggestions for marine economic development so as to establish and improve the marine economic system. The Slacks-based data envelopment analysis model (SBM-DEA model) is used to analyze the efficiency of the marine economy, and the undesired output is taken as the basis of calculation. Marine environmental protection is taken as an important link to the development of the marine economy. Then, the key strategic goals that are beneficial to short-term marine economic development are put forward and the long-term and short-term marine economic development goals are combined in order to better promote the development of China's marine economy.

2. Literature Review

In terms of financial support, technological improvement and marine economic efficiency, domestic and foreign scholars' studies have focused on the impact of financial support on the marine economy, the impact of financial support on technological progress and the impact of technological progress on marine economic efficiency. There are also studies related to policy optimization and technological aspects.

2.1. The Relationship between Financial Support and Marine Economic Efficiency

Currently, China is still in a relatively immature situation in terms of financial support in the ocean. Scholars' research on marine financial support possesses the following three characteristics. First, many scholars are studying the important topic of the relationship between finance and the development of the marine industry. There is currently a lack of professional marine financial support institutions to provide sufficient and continuous financial support for the marine industry in China, which hinders the development of the marine industry and makes it more difficult to improve the efficiency of the marine economy. However, the risk of marine investment has a negative influence on the development of the marine economy, which is mainly reflected in the large amount of investment capital, the long capital recovery cycle and the greater impact of natural disasters (such as tsunamis and earthquakes) on investment. From the research on marine economy and financial support for marine economic development, Ma J. (2021) [6,7] argued that marine capital investment and marine scientific and technological progress are the main factors for high-quality development of the marine economy. Relevant policy is put forward to strengthen the financial guarantee of the development of the marine economy and the investment in marine economic education. In terms of the development model of marine finance, Pan J. and Yan X.Q. (2012) [8–11]. proposed that interest rate liberalization promotes competition among the banking industry, makes the funds of the banking industry flow into the marine economy and optimizes the credit structure and stock scales. At the same time, it will promote the inflow of private capital into the marine economy to expand investment in the marine industry For marine financial institutions, Yao X.Y. (2012) [12] used the grey correlation degree to analyze the relationship between marine economic development and financial support and financial policy support. The problems of marine finance are the lack of professional financial institutions, innovation ability of marine financial products and the imperfect systems and policies on the development of ocean finance. In view of the low professional level of financial services, it is necessary to increase the innovation ability of marine financial products [13,14].

Financial support is mainly divided into three aspects: the contribution of financial support to marine-related enterprises, the contribution of financial support to the marine industry and the contribution of financial support to the development of the marine economy. Lv Z. and Li B. (2021) [15] proposed that the development of the marine economy should be enhanced by relevant foreign technologies. Based on financial investment, it can create diversified financial institutions and innovate the marine economic development system in line with socialism with Chinese characteristics. Special training for marine financial practitioners and marine financial technology innovation should be increased.

2.2. The Relationship between Technological Improvement and Marine Economic Efficiency

Shao Q. (2021) [16] clearly indicated that marine technological improvement is the main factor for China's marine economic growth of the future, and it has a directive function regarding the strategy of marine power in technological improvement and adjustment of the marine industry. The cyclical characteristics of marine technological improvement also have a negative impact on the adjustment of the marine industrial structure [17]. China's marine technology innovation capacity, marine researchers and scientific research funds are insufficient for marine science, and the scientific research institutions of the marine industry are small in scale, low in level and weak in strength (Yu D., 2020) [18]. The main problems of marine technological improvement are the efficiency of resource input allocation and the ability of transforming and applying technology. At the same time, the coastal industrial structure has a negative effect on the marketing of marine science and technology, and the optimization of scientific research and members of the marine industry are also important issues. Due to the different coastal areas in China, the relevant marine policies and technological investment are also different [19]. Therefore, it is necessary to strengthen the connection and cooperation between various coastal cities and jointly improve marine technological innovation. Further, ükrü Merey (2020) [20] analyzed increasing early investment in marine technological improvement and the industrialization of innovative technologies, which guided social capital into the field of blue finance in the development of the marine economy from the perspective of marine industry. At present, the research in this area is still at the theoretical and macro level and there is no specific activity of technological innovation.

2.3. The Relationship between Financial Support and Technological Innovation

Financial support for the application of artificial intelligence, big data technology and cloud computing technology in marine technological improvement will change significantly. In the financial support of technological innovation, Ren W. (2018) [21] measured the level of technological improvement supported by financial aspects. At the perspectives of technology and finance, they mainly studied the contribution to finance with technological infrastructure. With the increase in the amount of marine resources and energy, there are more and more explorations thereof, so the investment demand for marine technology is increasing. However, the current financial support for technological improvement is not enough, and the state needs to increase policy guidance to ensure financial support and marine technology coordinated development of innovation and mutual promotion. Financial support for technological innovation involves large loan terms and high risks. Carvalho A.B. (2021) [22] indicated that financial support has a greater impact on technological innovation in the spatial spillover effect of financial support for technological innovation, but there are great differences regarding technological innovation capabilities. Relying on the advantages of the Special Economic Zone, financial support for technological innovation is much higher than that of other regions in the Yangtze River Delta, eastern coastal cities and Hong Kong and Macau. At present, it is also improving the policy of financial support for technological improvement, and there are many studies on the application of financial support for technological improvement in the field of agriculture. However, as of now, financial support for technological improvement has not been extended to the field of marine economic development [23,24].

In summary, the above scholars have conducted separate research on the three aspects of financial support and technological improvement, technological improvement and marine economic development and financial support and marine economic development, but there is no research on the relationship between the three aspects. There is no empirical research and analysis, and the research remains on a theoretical level. This paper focuses on analyzing the relationship between them, and it analyzes the relationship between them by panel data and proposes more specific, effective and systematic plans and suggestions. With better use of financial support, we can strengthen technological improvement and further promote the development of marine economic efficiency.

3. Analysis of the Impact Mechanism of Financial Support and Technological Improvement on the Development of Marine Economy

3.1. Financial Support to Promote the Development of Marine Economy by the Utilization of Marine Capital

Stable and efficient financial support provides sustainable power for the development of the marine economy. Due to the different levels of economic development in China's coastal provinces and cities, the methods and levels of financial support are also different. There are higher economic development levels in Tianjin, Guangdong, etc. Coastal marine economic development is the central force that has primarily driven the increase in wealth since the reform and opening up of the economy. Additionally, the financial support for the marine economy and maritime trade is the same. However, financial support is invested in projects with high technical difficulty and complexity. The short-term investment recovery is low, and is not easy with such a project to generate sustainable and stable cash flow. Therefore, the project cannot obtain high profits, so financial support must be used in short-term profitable projects in the marine economy. Only in this way can the development of the marine economy be guaranteed [25,26].

3.2. Technological Improvement in Marine Economic Efficiency through Technological Innovation and Scientific Research Person Training

Technological improvement must adhere to the principles of gradual innovation, upgrading innovation and scientific innovation. It is not permitted to ignore technological research and development that can generate economic benefits in the short-term while directly making use of challenging technologies. For example, the smart ocean project in the Shenzhen Greater Bay Area will comprehensively drive the development of the ocean economy, including seven major fields and twenty-one specific directions. It has a promoting effect on the comprehensive development of the marine economy, but 21 specific directions mean that the technological part needs to be invested in 21 directions. In view of human and financial resources, financial support should be carried out in one to two core and key directions. That can ensure the support of technical persons and financial support to a large extent, generate a sense of competition and technological improvement can be completed in a relatively short period of time [27]. At the same time, science and technology need not only to be independently developed but also cooperative with other countries. We need to form a multi-national and multi-disciplinary technology-leading scientific research team, deepen international marine cooperation and participation in global marine governance and build a marine power.

3.3. Financial Supports Promote Steady Growth of Marine Economic Efficiency by Strengthening Capital Investment in Scientific Research and Technological Innovation

The improvement to marine economic efficiency will attract more funds to the marine industry, and sufficient funds are also the foundation for ensuring technological improvement. How to improve marine economic efficiency is an important link and key issue in current economic development. China's marine economic efficiency is also affected by the level of local economic development. With the introduction to carbon neutrality and carbon emissions, more and more attention has been paid to carbon emissions from relatively developed cities, such as Guangdong and Tianjin, and more attention has been paid to the use of clean energy. The environmental protection requirements are more strict, which has prompted the marine economy of these cities to adopt higher efficiencies. The adjustment and optimization of the marine industry structure plays an important role in the improvement in marine economic efficiency. Improving high-tech and new technology and transforming traditional industries, the development of emerging industries and high-tech industries can improve the efficiency of the marine economy [28].

4. Empirical Research

4.1. Data Sources

This paper undertakes an empirical analysis based on annual data from 2009 to 2018 in China's coastal provinces and cities. The data come from the China Statistical Yearbook, China Financial Statistical Yearbook, China Marine Statistical Yearbook and regional Statistical Yearbooks. Matlab 2016 software (MathWorks, Natick, MA, USA) was used for the calculation of marine economic efficiency and the BVAR model, while the rest of the empirical process was completed with Stata 15 software (StataCorp LLC, College Station, TX, USA).

4.2. Variable Selection

In this paper, financial support, technological innovation and marine economic efficiency are selected as the basic data to calculate the BVAR model.

4.2.1. Financial Support Indicators

Financial deepening indicators are selected by the bank capital deepening rate (BFD), the ratio of RMB loans balances in banks and financial institutions to GDP at the end of each region, which represent the deepening level of financial capital. This paper selects the year-end RMB loan amount and GDP of each financial institution in each province and city in the coastal region from 2009 to 2018. The data source is the China Financial Yearbook. This paper selects social fixed asset investment, local fiscal expenditure and various loans (balances) of banking financial institutions as the financial support for the region. At the same time, it divides the marine industry GDP by the proportion of marine industry GDP and regional GDP to estimate the regional GDP, and it compares the financial support marine amount of the regional GDP to obtain the economic efficiency value of regional financial support. The results are shown in Table 1:

Table 1. Economic efficiency value of financial support from 2009 to 2018.

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Tianjin	2.21	2.22	2.23	2.28	2.33	2.40	2.56	2.63	2.54	2.69
Hebei	1.40	1.41	1.56	1.69	1.83	2.01	2.26	2.33	2.40	2.43
Liaoning	1.93	1.56	2.01	2.13	2.20	2.19	2.57	2.23	2.23	2.18
Shanghai	2.37	2.41	2.41	2.50	2.53	2.50	2.62	2.62	2.66	2.69
Jiangsu	1.60	1.52	1.67	1.77	1.83	1.88	1.92	1.96	1.99	1.95
Zhejiang	2.32	2.10	2.20	2.33	2.40	2.48	2.55	2.51	2.44	2.39
Fujian	1.54	1.52	1.78	1.92	2.00	2.12	2.22	2.20	2.21	2.11
Shandong	1.43	1.54	1.50	1.52	1.65	1.72	1.82	1.86	1.87	1.88
Guangdong	1.93	2.08	1.55	1.28	1.72	1.77	1.79	1.95	2.03	2.06
Guangxi	2.26	2.29	1.98	2.13	2.04	2.09	2.24	2.32	2.61	2.56
Hainan	1.38	2.06	2.21	2.44	2.66	2.72	2.97	3.17	3.29	3.33

Figure 1 shows that regional financial inputs are greater than regional outputs, and regions have more inputs in finance from 2009 to 2018. However, relative to outputs, this is not as impactful as the efficiency of financial support enhancement. The magnitude of financial support economic efficiency of 11 cities is basically floating from zero to 3.50. Lower economic efficiency indicates that the efficiency of financial support is weaker. Higher economic efficiency indicates that the financial support is stronger.

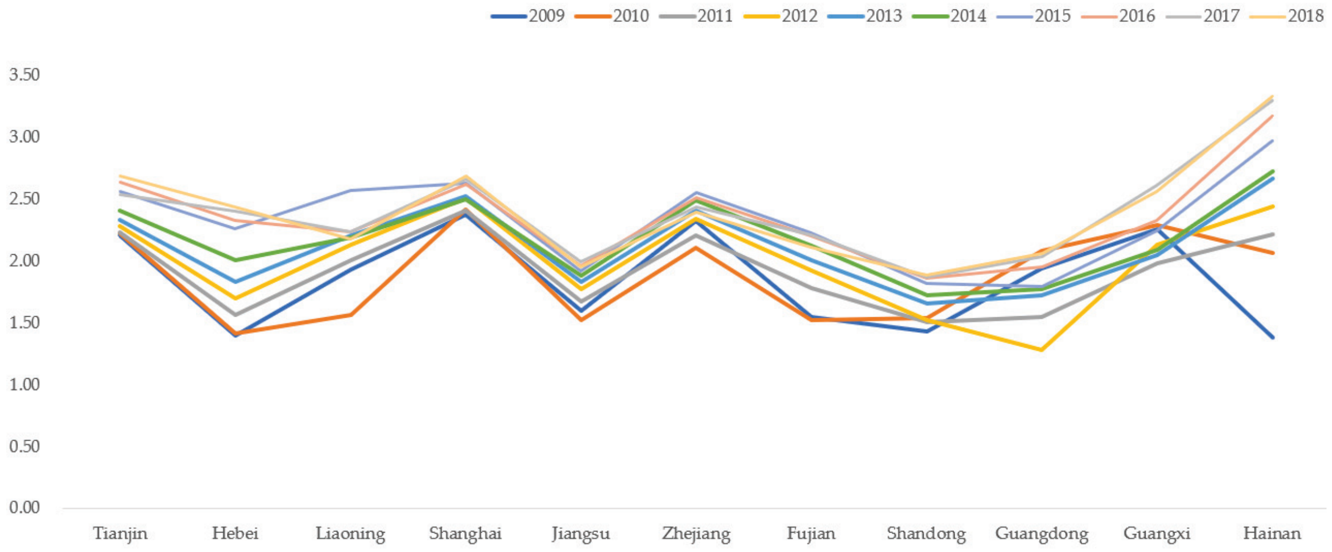

Figure 1. Financial support efficiency of China's coastal cities from 2009 to 2018.

The overall proportion fluctuates between 2 in financial support for each province and city. It indicates that the coastal provinces and cities have greater financial support, which is greatly related to China's policy factor of giving priority to the development of coastal areas during the reform and opening-up period; mainly, it is greater in Hainan, Guangxi, Zhejiang, Shanghai, Tianjin and other regions. Compared with financial support, the situation of output is not very good; the proportion of gross product of the sea is especially small (shown in Figure 2) [29,30].

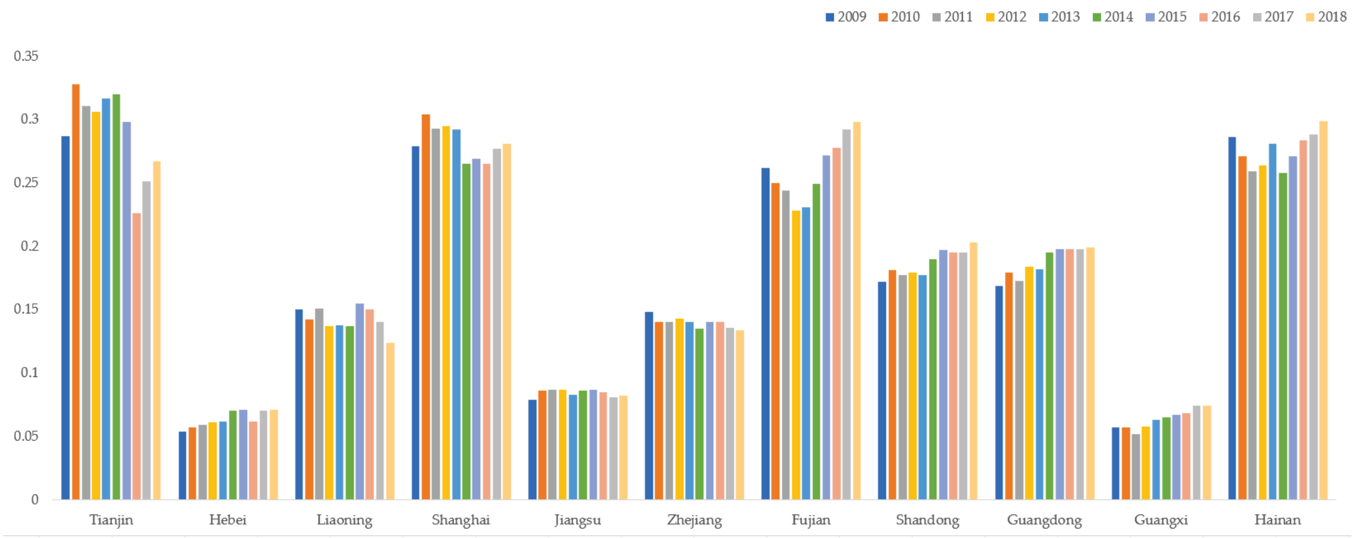

Figure 2. Proportion of marine GDP to regional GDP in coastal provinces and cities.

4.2.2. Technology Innovation Indicators

In this paper, we choose the internal expenditure of R and D funds and the income of marine research institutions as the technological innovation inputs of the marine economy. We determine the proportion of the technological innovation input of the marine economy to the GDP of the marine economy, as shown in Figure 3.

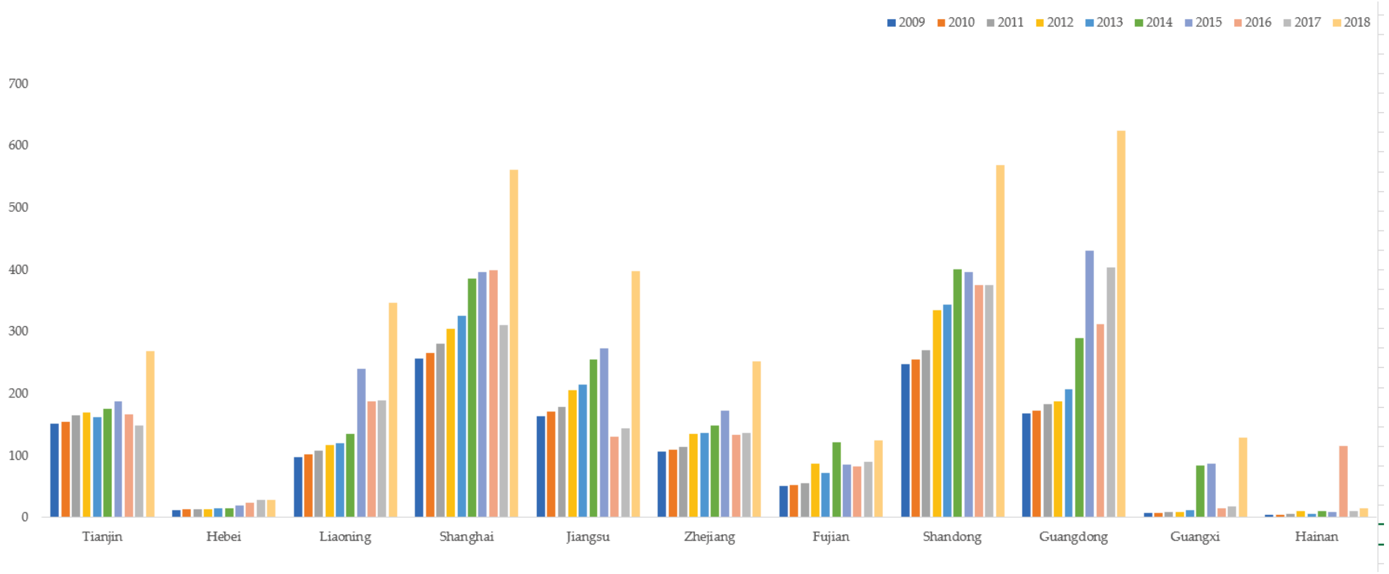

Figure 3. Marine technology input chart.

As can be seen from Figure 3, Guangdong Province invested more in science and technology in 2015 and 2018. Shanghai and Shandong Provinces increased their investment in science and technology year by year, while Hainan Province invested more in science and technology in 2016. It shows that marine technology increased greatly in 2016 [31,32].

From the Figure 4, it can be seen that China has invested more in science and technology for Guangxi and Hainan and focused on developing Hainan's economy.

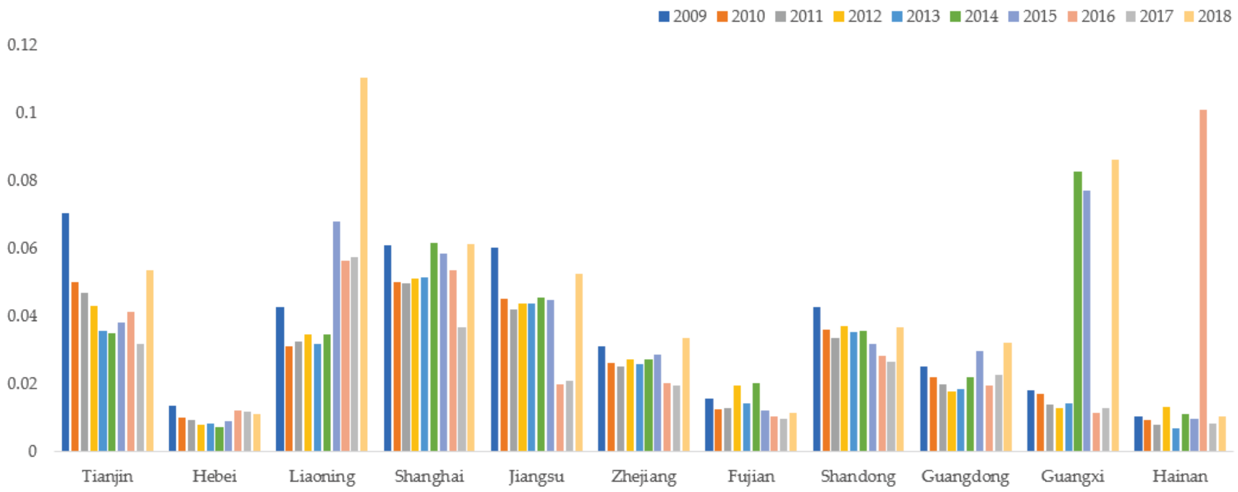

Figure 4. Chart of marine technology investment as a share of GDP.

4.2.3. Marine Economic Efficiency Indicators

The following table shows what this paper selects in terms of inputs with the coastal provinces and cities from 2009 to 2018.

The Table 2 shows that the most critical factor of the productivity of the marine economy is the input of capital and labor. Since the ocean itself produces energy, the ocean development itself for energy consumption is relatively small, so ignore the energy input. The desired output is the gross marine product, and the non-desired output is wastewater, waste gas and waste residues. Marine pollution is a very important element, so the non-desired output has an important impact on the efficiency of the marine economy.

Table 2. Indicator system.

Indicator 1	Indicator 2	Indicator 3
Inputs:	Capital:	Total social fixed investment (billion yuan)
	Labor:	Employment of sea-related personnel (people)
Expected Output:		Gross marine product (billion yuan)
Non-Expected Output:		Wastewater (million tons)
		Waste residue (million tons)
		Exhaust gas (million tons)

4.3. Model

4.3.1. SBM-DEA Model

In this paper, the data envelopment analysis (DEA) model is selected to measure the eco-efficiency of China's logistics industry, and it is selected in the DEA method of the SBM model with the problem of evaluating the efficiency of the existence fee expected output [33]. In this paper, the SBM-DEA model based on Jin-woo [34] is analyzed, and the SBM models considering N in inputs (x), M desired outputs (y), and I non-desired outputs (b) is as follows.

$$Min\theta = \frac{1-\frac{1}{N}\sum_{n=1}^{N}\frac{s_n^x}{x_{n0}}}{1+\frac{1}{M+I}\left(\sum_{\mathrm{m}=1}^{M}\frac{s_m^y}{y_{m0}}+\sum_{i=1}^{I}\frac{s_i^b}{b_{i0}}\right)}$$
$$s.t.\begin{cases}\sum_{\mathrm{k}=1}^{K} z_k x_{nk}+s_n^x=x_{n0}, n=1,2,\ldots,N\\ \sum_{\mathrm{k}=1}^{K} z_k y_{mk}+s_m^y=y_{m0}, m=1,2,\ldots,M\\ \sum_{\mathrm{k}=1}^{K} z_k b_{ik}+s_i^b=b_{i0}, i=1,2,\ldots,I\\ \sum_{\mathrm{k}=1}^{K} z_k=1\\ s_m^y\geq 0, s_n^x\geq 0, s_i^b\geq 0, z_k\geq 0\end{cases} \tag{1}$$

where θ is the eco-efficiency value of the logistics industry, taking values in [0, 1]; s_n^x, s_m^y, and s_i^b, respectively, slack for input factors, desired outputs and undesired outputs.

4.3.2. BVAR Model

VAR model studies the econometric model of multi-variable time series, which uses the current variable in the model to perform regression on the lag variable. The mathematical formula for VAR model is as follows [35]:

$$y_t = \alpha_1 y_{t-1} + \alpha_2 y_{t-2} + \cdots \alpha_p y_{t-p} + \beta x_t + \varepsilon_t, t = 1, 2, \cdots T \tag{2}$$

y_t is the n-dimensional endogenous variable vector. x_t is the n-dimensional exogenous variable vector. P is the lag order. $\alpha_1, \cdots, \alpha_p$ is $(n \times n)$ matrix. β of $(n \times m)$ matrix is the estimated coefficient matrix. ε_t represents $(n \times 1)$ white noise.

However, VAR model also has disadvantage that it ignores prior information. Traditional VAR requires a certain number of parameters, which leads to the problem of "parameterization". BVAR model uses a simple method to solve the problem of VAR model over-parameterization. The BVAR expression is as follows [36]:

$$y_t = \alpha_1 y_{t-1} + \alpha_2 y_{t-2} + \cdots \alpha_p y_{t-p} + \delta + \varepsilon_t, t = 1, 2, \cdots T \tag{3}$$

where y_t represents the $(n \times 1)$ vector containing n elements in period t. δ is the $(n \times 1)$ constant vector. α is the coefficient matrix, including financial support, technological improvement, marine economic efficiency and other variables. BVAR requires the test of prior information. According to Litterman, the prior distribution can be assumed to be Minnesota prior distribution due to the lack of clear prior information. If all elements in the coefficient α matrix satisfy the unit root U(1) prior distribution, then the mathematical expectation expression of all elements in the coefficient matrix is:

$$E[\alpha_{ij}^{(s)}] = \begin{cases} 1, \mathrm{IFs} = 1, \mathrm{i} = \mathrm{j} \\ 0, \mathrm{IFs} \neq 1, \mathrm{i} \neq \mathrm{j} \end{cases} \tag{4}$$

The formula shows all elements in the coefficient α_{ij} matrix of mathematical expectation only when a first order lag is 1; others are supposed to 0. In fact, all coefficients in the coefficient α_{ij} matrix of prior distribution are assumed for non-stationary AR (1) process.

4.4. Model Correlation Analysis

4.4.1. Marine Economic Development Efficiency Analysis

The marine economic efficiency of the Figure 5 is calculated by the SBM-DEA model. It can be found that the economic efficiency of Guangdong is close to 100% in 2018, which indicates that the input–output efficiency of these regions is very high. The input can basically be recovered, but the situation in other regions, such as Tianjin, Hebei, Liaoning, Zhejiang, Fujian and, especially, Guangxi is not very good. The economic efficiency of Hebei and Liaoning Bohai Economic Circle is not very high. Perhaps this is because Liaoning is in the old industrial base of the northeast. There are more inputs for marine aspects, but the output is not as good as Guangdong and Shandong regions. Although the economic efficiency of Shanghai is slower than that of Guangdong, the growth is very obvious from 2009 to 2018. Shanghai ocean GDP has been in the forefront of the country for many years, and it has advanced technology, R and D and R and D teams of ocean universities.

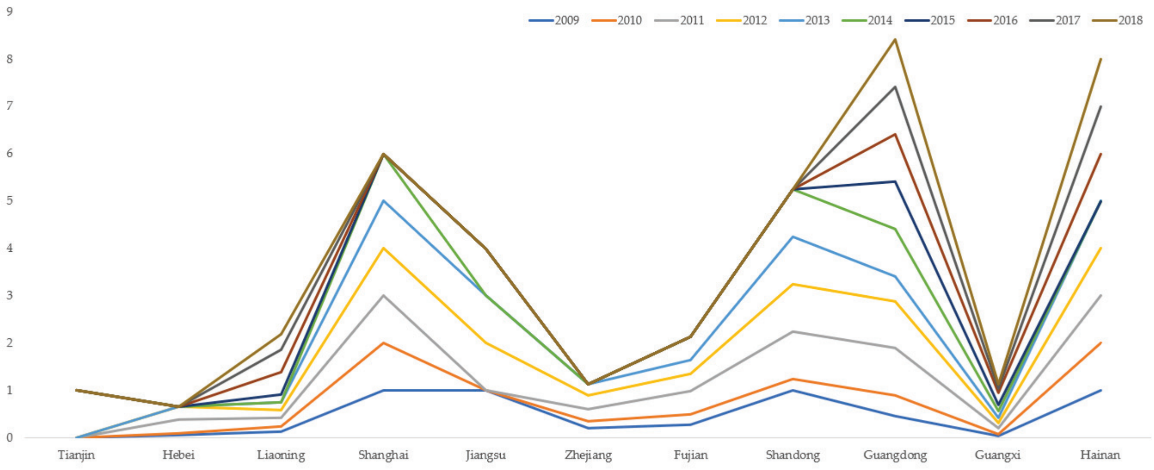

Figure 5. Marine economic development efficiency stacked chart.

Hainan organized and implemented 175 projects of the National Natural Science Foundation of China, an increase of 18.2% over the previous year. A total of 3669 patents were applied for the year, an increase of 17.4%, granting 1938 patents, and an increase from 5.9%. There are seventy-four newly recognized high-tech enterprises, four new provincial engineering technology research centers, three provincial key laboratories and one national key laboratory. All kinds of professional and technical personnel were added, 170,000 people, an increase of 12.6%. The provincial ministry jointly built "the South China Sea Marine Resources Utilization State Key Laboratory", realizing zero breakthrough in the province's university states laboratory. The first discovery of coral debris is a new process of coral reef biology and ecology and provides new technical support for the restoration of islands and reefs. The economic efficiency of Hainan is very high.

China's investment in science and technology is still insufficient, and there is still a large gap between China and developed countries, such as those of Europe and America, in general. The development of marine technology and the exploitation of resources not only needs to maintain the ecological balance but also needs to consider various factors, especially the balance of the marine economy on the basis of not destroying the ecological balance. For example, the "311" earthquake in Japan caused a nuclear leak that greatly polluted the marine environment. Pollution requires more money to be dealt with, and the cost of treatment is very expensive. The development of marine resources in China is still in a preliminary stage, and the current investment in science and technology mainly lies in transportation and the development of marine biology and marine wind power resources.

To analyze the efficiency of the marine economy from an industrial perspective, this paper adopts a new approach, using the input–output method. At present, China develops a profitable marine economy mainly in marine aquaculture, marine oil and gas, sand and salt industry, ship to repair, transportation, international tourism, etc. Marine aquaculture is the primary marine industry. Marine oil and gas, sand and mining, salt industry, ship repair and shipbuilding belong to the secondary marine industry. Transportation and international tourism and other commercial services are classified as the tertiary marine tertiary industry [37]. Figure 6 shows that the added value of China's marine primary industry is RMB 389.6 billion in 2020, the added value of secondary industry is RMB

267.41 billion. The added value of the tertiary industry is RMB 4937.3 billion, accounting for 4.9%, 33.4% and 61.7% of the marine GDP, respectively.

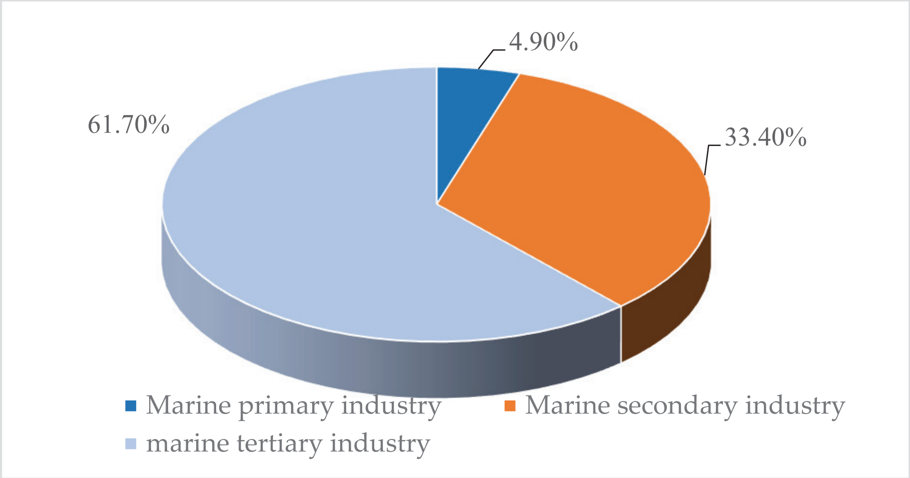

Figure 6. The proportion of the three major marine industries in 2020. Data source: General Administration of Customs of China.

The primary industry of marine fisheries is similar to the primary industry of agriculture in China. However, it has the same drawbacks as agriculture. Although the development of technology has improved the time and productivity of production, it cannot change the area of the land or the fishery itself. There is basically no difference in the production of products available for sale per unit acreage. Mechanization and intelligence have saved labor time to a large extent, but they bring the risk of unemployment for workers [38].

Marine secondary industry is mainly marine resources and energy industry. The development of marine resources and energy has high technical requirements. A great deal of money is needed in the research of technology. The safety of resources and energy needs to be maintained in the process of exploitation. It cannot be over-exploited according to damage to the environment.

The marine tertiary industry provides good profit in the best position, mainly in transportation and international tourism [39]. In transportation, the development of cross-border e-commerce has been a major impetus to international marine transportation. It will increase as Chinese manufacturing enjoys its price advantage in foreign markets. In international tourism, tourism is in the doldrums because of COVID-19. Marine tourism generates major gains and boosts related industry chains, such as housing, restaurants, photography, etc. It is an immediate consumption type of a short payback period. The damage to tourism of the environment is also shallow. It can be controlled and prevented as long as reasonable control and quality education for tourism personnel are carried out [40].

In summary, the marine tertiary industry contains a large proportion of the marine economy and plays an important role in the efficiency of the marine economy [41,42].

4.4.2. T-Distribution and Descriptive Statistics

Table 3 clearly shows that n = 11 and T = 10. n > T, so this is short panel data. Table 4 shows the descriptive statistics for of the data.

Table 3. Distribution of T.

Distribution of T_i:	Min	5%	25%	50%	75%	95%	Max
	10	10	10	10	10	10	10

Table 4. Descriptive statistics.

Variable	Observation	Mean	Standard Deviation	Sum	Minimum	Median	Maximum
Fin	110	2.1425	0.4040	235.68	1.27565	2.1810	3.3298
Tec	110	0.0319	0.0209	3.51	0.00707	0.0285	0.11022
Sea	110	0.3627	0.4214	39.90	0	0.15794	1

4.4.3. Smoothing Test

An LLC smoothness test was performed on the data, and the results are shown in the Table 5.

Table 5. Smoothing test.

Variables	Fin	Tec	Sea
Statistic	−3.8661 ***	−5.3900 ***	−3.6588 ***
p-Value	(0.0001)	(0.000)	(0.0001)

Note: the values of the table correspond to the adjusted t-statistic of the LLC test and the corresponding *p*-value of the probability of significance. *** significant at the 10% levels.

From the results, it can be seen that each variable is significant at the 1% level and passes the significance test, indicating that the data are stable.

4.4.4. Co-Integration Test

Table 6 shows that the Kao test and Pederoni test find that the significance level is clustered within 10%, although the Westerlund test is not clustered. It is rejected in the original hypothesis of no cointegration relationship between the variables. There is an equilibrium relationship between financial support, technological progress and marine economic efficiency.

Table 6. Co-integration test.

	Statistic	*p*-Value
Kao Test	−3.3859 ***	0.0004
Pedroni Test	−4.7248 ***	0.0000
Westerlund Test	−0.0074	0.4970

Note: the values of the table correspond to the unadjusted modified DF-t statistic of the Kao test, the ADF-t statistic of the Pedroni test, the statistic of the Westerlund test and the corresponding significance level *p*-value; *** indicate significant at the 10% levels.

4.4.5. GMM Test

Table 7 shows that financial support has a significant positive impact on marine economic efficiency, while marine economic efficiency has no significant impact on financial support; financial support has a significant negative impact on technological improvement, while technological improvement has a significant positive impact on financial support. For themselves, financial support and marine economic efficiency have a significant positive impact, but technological improvement has no significant impact.

4.4.6. Impulse Response Function Analysis

It can be seen from Figure 7 that the impact of financial support, technology improvement and marine economic efficiency individually is positive and gradually tends to zero as time passes. The impulse of technological improvement on financial support is opposite to the impact of financial support on technological improvement and tends to zero gradually. In the second period, technological improvement has a positive impact on financial support. Technological improvement and development improve productivity and attract capital.

However, the influence of technology is gradually weakened and the ability to attract capital becomes less and less with the advancement of time. Financial support has a positive effect on marine economic efficiency, but marine economic efficiency has a negative effect on financial support. The impact of financial support on marine economic efficiency reaches the maximum in the third period. The impact of marine economic efficiency on financial support reaches the minimum value in the initial stage, and the impact gradually tends to increase. The main reason is that the efficiency of the marine economy will be improved in the short-term when the marine industry receives financial support. The impact on the efficiency of the marine economy will gradually weaken after reaching the peak from two to three years. Due to the inertia effect, the initial capital investment makes the cash flow renew, and the enthusiasm for the staff engaged in the marine economy is further improved, improving the economic efficiency. The impact of technological improvement on marine economic efficiency has the same trend as that of marine economic efficiency on technological improvement: both of them converge at zero after reaching the peak of the second period, and both have positive impacts. The reason is that technological progress and marine economic efficiency promote each other and tend to be synchronized.

Table 7. GMM test results.

		Statistic	***p*-Value**
lnFin	Sea	1.65 *	0.099
	lnFin	5.81 ***	0.000
	lnTec	−2.79 **	0.005
lnTec	Sea	0.88	0.376
	lnFin	3.6 ***	0.000
	lnTec	−1.36	0.173
Sea	Sea	3.93 ***	0.000
	lnFin	1.22	0.222
	lnTec	−1.30	0.195

Note: probability of significance *p*-value; ***, **, * denote, respectively, significant at the 10%, 5% and 1% levels.

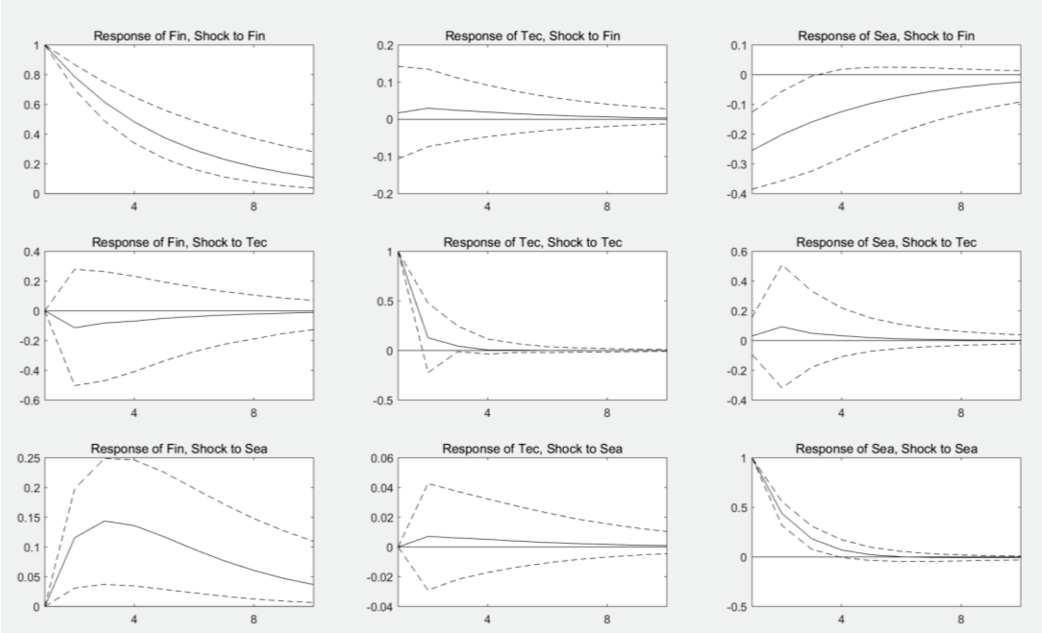

Figure 7. BVAR impulse response graph.

5. Conclusions and Recommendations

From the above empirical evidence, the main problem of ocean economics is that the total output value of ocean economics is too low. The influence of financial support and technological improvement in marine economic efficiency usually remains in the short-term, and the influence gradually decreases with the advancement of time. Therefore, financial support often stays in the short-term, and there is no long-term stable financial support. The effect of marine economic efficiency on financial support is negative, which proves that the improvement in marine economic efficiency does not provide a new round of financial support. It indicated that there are problems regarding the economic cycle [43]. After marine economic efficiency improved, improvement in marine economic efficiency did not culminate in a new round of financial support. It is necessary to improve the marine industry structure and complete a new cycle. Our suggestions for the above issues are as follows [44,45].

5.1. Science and Technology to Promote the Development of Marine Wealth Management

The current technology development and investment lies in the exploration of marine resources and energy, resulting in the problem of long payback periods for many inputs. Therefore, economic development was promoted by improving marine financial technology, improving and strengthening financial services for marine economic development and promoting the transformation of the marine economy in terms of quality and efficiency. It is important to support the training, screening and reserve for high-quality and mature sea-related enterprises [46,47]. In insurance, it strengthens the standardized development of various types of mutual insurance, explores catastrophe insurance and reinsurance mechanisms and accelerates the development of shipping insurance, coastal tourism insurance and environmental liability insurance. Necessary are exporting credit insurance coverage and encouraging insurance funds of professional asset management institutions in order to increase investment. New green fund products, green ABS, green ETF, etc. must be created. Regarding green ABS, green ABS can lower the financing threshold of green enterprises and enable them to obtain low-cost financing. Green ABS is based on cash flow for repayment; once the cash flow is insufficient, the problem of repayment difficulties will arise [48]. Therefore, green ABS companies are required to ensure sustainable growth of earnings [49]. Once sustainability is not guaranteed, green ABS will collapse. The current government policy should provide guidance as Chinese individual investment is not very trusting in the ocean. The Chinese government needs to attract more corporate, private equity, fund and institutional investors to invest in green ABS. We believe that, if this project is conducted well, it will become a financial product of particularly Chinese characteristics. Because of the unique macro-control of socialist countries, they can largely guarantee the stability of investment and the controllability of risk, but the disadvantage of conducting green ABS in socialist countries is the lack of economic dynamism to guarantee sustained and stable profitability. This part can be borrowed from Warren Buffett's investment philosophy, as well as the portfolio concept. China's green ABS is in its infancy, so the implementation of dynamic green ABS is a clear market choice. For example, one aspect is to choose a marine product portfolio while incorporating resources from multi-period hotspots to drive the development of the marine industry. It will help to build the infrastructure of the marine industry and carry out multi-cultural forms of marine cultural exchange. It also drives the development of marine entertainment culture [50,51].

5.2. Financial Supports for the Development of Marine Enterprises

Financial support should be based on guaranteeing the profitability of marine enterprises. There are two main aspects in the profitability part: promoting marine enterprises to improve profitability and guaranteeing marine enterprises to reduce losses. The two aspects are one thing on the surface, but they are not in reality. In terms of the use of financial support funds, they are divided into the following categories.

5.2.1. The Volume of Foreign Trade Cargo Transportation in Marine Logistics Industry

In 2021, the price of maritime freight constantly broke new highs, and container demand is tight because of COVID-19. As a result, many container enterprises have been able to obtain higher profits, and the amount of capacity has increased [52,53]. Cross-border e-commerce development leads to people engaging in more online shopping, resulting in container enterprises profitability soaring. The core product of Global Shipping Business Network (GSBN) has been putting into production application for 11 ports at home and abroad. The technology upgrade of paperless cargo that was released enables one-digital ecological diversity and creates green low-carbon intelligent shipping [54].

It is also an important profit source of the new terminal business market in the port business, and the port miscellaneous fee is also a large income. Table 8 lists the port miscellaneous charges for a 20-inch container from Dalian port, and the data are provided by a company [55,56].

Table 8. Port miscellaneous charges at Dalian port.

Fee Type	Fee (CNY)
Terminal Operation Fee	566
VGM filing fee	164
Document Fee	50
Document processing fee	450
Unloading Fee	50
Equipment handover order	50
Booking Fee	65
Operating fee	100
Sea freight	50
Packing fee	2840
Customs clearance fee	350
Handling fee	200
Labor packing fee	110
Pallet fee	100/PCS

In port and port miscellaneous fees, the profits of the terminal business are quite objective. The enterprise is not required to undertake any risk with the application of paperless equipment to enhance the cost of the transport industry. The cost of a paper bill of lading is 0, but it requires the domestic express of up to 50 yuan. However, the electric release bill of lading reached 350 yuan. This electronic form does not appear to have any cost, so this profit is quite large. However, it does provide convenience for the transported enterprises, especially the transport of inexperienced small- and medium-sized enterprises [57]. On the other hand, if there is no need to import or export goods, it is impossible to obtain profits in this area. The import and export of goods is affected by the sales and production situation of enterprises, and it has strong instability [58].

5.2.2. Accelerate the Pace of Science and Technology Empowerment and Enhance the Strength of Enterprise Science and Technology

The development of fisheries is extremely similar to agriculture in that both produce limited output with limited resources.

The output of a fish pond is quickly limited, and too much or too little placement of juvenile fish will affect the output. The output of fisheries remains relatively stable when not subject to mega-accidents. The overall annual revenue of the company does not differ much when the fisheries company is not affected by additional factors [59]. However, there is a greater impact on the fishing industry in the current situation of international high seas fishing and increasingly strict fishing policies. Compliance with legal fishing has become the focus of the current fishing business operations.

5.3. Insurance against Marine Business Services to Promote the Development of Marine Economy

In terms of insurance, marine insurance is an important part. By the end of 2021, a company in Dalian, Liaoning Province has a cumulative premium income of 372 million yuan, payout expenditure of 546 million yuan, providing nearly 4.9 billion yuan of risk protection against the marine floating raft breeding facilities insurance, mariculture wind index insurance, aquatic seed production insurance, algae wind index, net fish breeding insurance, factory fish breeding insurance, marine fish breeding insurance, marine fish breeding additional loss, netting, and transshipment in 8 years of insurance products. It can be clearly seen that insurance plays an important role in the development of the marine economy to protect the development of marine enterprises. From the amount of insurance payout, the profit of this insurance company = 372 − 546 = 114 million yuan, of which 114 million yuan is also known as the enterprise loss. This company has a large loss in the main business within a year, so how should the business continue to operate? In terms of financial support and policy support, we must consider the actual situation of the enterprise to support the company. Sometimes, despite blindly investing a great deal of money, the enterprise for innovation and the transition to business is not suitable for the insurance operation, which is a great risk for insurance companies [60].

5.4. Tourism Cultures

Cultural tourism has been the focus of China’s marine economy development. Cultural tourism is in the short payback period, with low input costs and in line with the investment concept of the majority of Chinese investors or investment enterprises “to earn a block of money”. Therefore, marine tourism is currently the most profitable part of the marine economy [61,62]. For this part, more tourism related to coastal cities is important to promote the development of the entire coastal economy. Tourism leads to the development of related catering, hotel and service industries, but there are some areas where tourism is not very well developed and does not make good use of infrastructure for tourism development. Providing more creative tourism and culture industry is the top priority of developing marine tourism at present. The scenes of some tourist places cannot meet people’s needs because some are built too luxuriously. People cannot enjoy all the quality services in a limited time. With the advancement of time, economic changes and changes in people’s needs, the original infrastructure cannot meet the needs of people [63]. Therefore, in addition to the construction of fast-track themed and creative tourism and cultural festivals, in order to facilitate the combination of green ocean and local culture, the culture of the specific country has become a major hot spot regarding the development of the current marine tourism industry and can lead to significant consumption, thus enhancing the development of the local marine economy [64].

5.5. The Development of Marine Biology Will Generate a New Industrial Revolution in the Development of Marine Economy

At present, the development of biopharmaceuticals in China is strongly supported in the context of the COVID-19 pandemic and the outbreak of monkeypox virus in the world. Biopharmaceuticals are becoming more and more essential parts of the biological field [65]. From independent laboratories to manufacturing to various sales scenarios, each part requires significant technical input. In addition to the existing biopharmaceuticals, as the economic development and improvement in people’s living standard occur, the spread of various rare diseases worldwide is increasing. People’s demand for medicine is increasing, as is the risk of emergence. Therefore, the development of marine biomedicine provides new opportunities for China’s economy and even for the surrounding world. The wide variety of marine species is of great benefit to biomedical research, thus building a “blue medicine bank” for China’s marine economy.

In this paper, the BVAR model is selected for analysis. The BVAR model is a traditional econometric model that is widely used in economics papers. Compared with other models, BVAR can effectively solve the problem of VAR transition parameterization and can be effectively applied to the field of regional economy. It is made up of a single variable extended to a multivariate time series variable vector autoregressive model [66]. It can also examine the impulse responses of variables to variables. With the development of the economy and the progression of time, the authors will use more machine learning algorithms to further study this topic in the future.

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The Impact of Trade Facilitation on Cross-Border E-Commerce Transactions: Analysis Based on the Marine and Land Cross-Border Logistical Practices between China and Countries along the "Belt and Road"

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Abstract: In the post-epidemic era, cross-border e-commerce has become a new growth point for global foreign trade. Unlike traditional trade, which is dominated by marine transport, cross-border e-commerce transactions have high requirements for both marine and land transport, and the scale of their trade is accordingly limited by the level of trade facilitation i.e., the convenience of cross-border logistics in bilateral trading countries. Based on transaction cost theory, this article takes cross-border e-commerce transactions between China and countries along "The Belt and Road" as the core of the study. From the perspective of marine and land transport timeliness, the theoretical framework is constructed using the marine and land logistics infrastructure, customs clearance environment, government–governance environment, and cross-border logistics services as the main influencing paths; the GMM method is then applied in order to conduct a study on the impact of trade facilitation on the scale effect of cross-border e-commerce. The study finds that marine and land transport infrastructure has the strongest impact, with customs clearance environment and government–governance environment having the second strongest and comparable impact. The findings of the study further clarify the differences in the application of different cross-border logistics facilitation measures, and provide a theoretical basis for improving the timeliness of cross-border e-commerce transactions and reducing trade costs as well as a reference for the realization of land–sea integration and land–sea interconnection under "The Belt and Road" initiative.

Keywords: cross-border logistics facilitation; marine transport; cross-border e-commerce; China railway express; SYS-GMM estimation

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1. Introduction

The current global multi-billion-level consumer market tends to be e-commerce. At the same time, "The Belt and Road" initiative put forward by the Chinese government has deepened the integration of countries along the route with China's ocean economy, and has promoted cross-border e-commerce to become a new driving force for global trade growth. In traditional goods trade, marine transportation is the mainstream mode of transportation due to large transaction volumes. However, marine transportation is easily affected and restricted by natural conditions such as waterway hydrological conditions and meteorological conditions. In cross-border e-commerce, due to the small transaction volume of a single order and the higher requirements of the consignee on with respect to the timeliness of transportation, marine–land transportation is the mainstay for ensuring that goods can be delivered to customers on time. To this end, some companies rely on border ports and cross-border logistics channels to set up border warehouses, or set up overseas warehouses in destination countries to better meet customer consumption experience. Because overseas warehouses are restricted by the political environment of a country's market, their establishment is not suitable for all countries along the "Belt and Road". Correspondingly, the development of cross-border e-commerce transactions will also be affected and restricted by a country's trade facilitation environment. In the past eight years, China's cross-border e-commerce transaction scale has reached RMB 12.5 trillion, an increase of 11.6% year-on-year, and the transaction scale accounted for 38.86% (Figure 1). Driven by the "The Belt and Road" policy, the General Administration of Customs of China has successively issued a series of trade facilitation measures which have continuously optimized the marine economic environment and effectively reduced transaction costs and expenses such as cross-border shipping and land transportation. It is particularly necessary to explore the impact mechanism of cross-border e-commerce transaction scale growth against the trend of cross-border logistics facilitation, as this is the core of the new era around the practice of marine and land cross-border logistics.

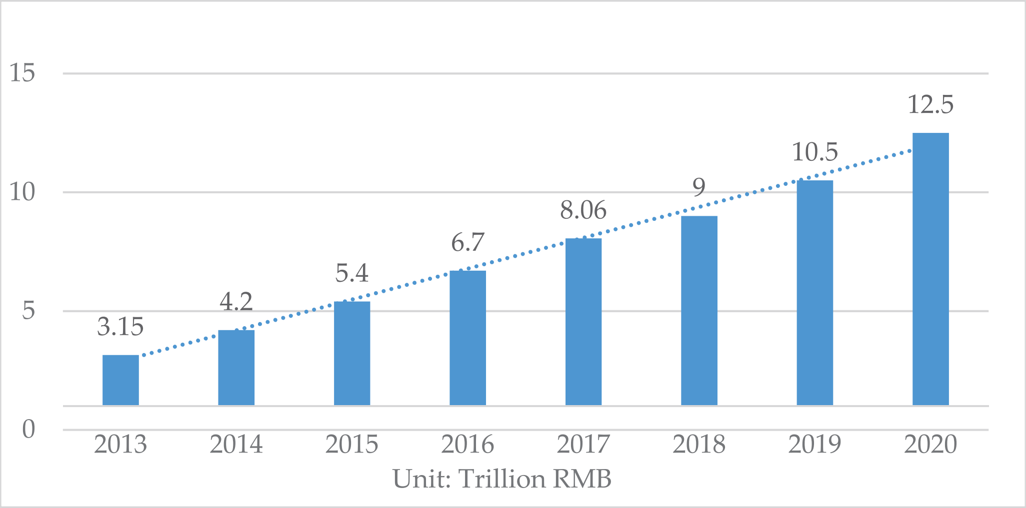

Figure 1. Cross-border e-commerce transaction scale in China, 2013–2020. Data source: China Network Economy Platform Data Center.

The essence of trade is information flow, capital flow and logistics. In terms of information flow, compared with traditional foreign trade transactions cross-border e-commerce transactions use various forms of carriers to collect, publish and exchange information through e-commerce platform websites so as to complete transaction negotiations in the most convenient way, thus realizing efficient transmission of information flow. Comparing capital flow with traditional trade settlement methods, its complexity is more focused on dealing with the remittance of different currencies of different overseas buyers and the compatibility of various types of different localized payment methods, mainly involving settlement and billing issues; however at present, cross-border payment platforms such as Stripe, PayPal, Amazon Pay, Payoneer, Alipay, etc., have realized the settlement of payment for goods on both sides. It can be seen that in terms of information flow and capital flow, cross-border e-commerce transactions can bring lower transaction costs than traditional trade. However, in terms of logistics, cross-border e-commerce transactions face bottlenecks in development similar to traditional trade transactions. Examples include cumbersome customs clearance procedures, poor infrastructure at marine logistics ports, low quality of land transport services, low efficiency of port crossings, and other cross-border logistics non-facilitation environmental issues. In view of this, the WTO promulgated and implemented the Trade Facilitation Agreement in 2017, aiming to achieve simplification and transparency of trade procedures in member countries to facilitate the free flow of goods and services.

At present, the world's economic and trade development is in a very sensitive period; unilateralism and trade protectionism are expected to rise further, leading to an increase in non-tariff barriers in the future and a more severe export trade situation; coupled with the secondary impact of the epidemic, this results in downward pressure on traditional trade transactions and many negative factors overlapping [1]. At this time, the flexibility and convenience of cross-border e-commerce online transactions highlight the advantages of the future may usher in a new round of opportunities and challenges. How the government, e-commerce enterprises and consumers can rely on the optimization of the trade facilitation environment to carry out cross-border e-commerce transactions is a pressing issue worthy of in-depth consideration and exploration.

In view of this, the present paper constructs a conceptual model of the impact of trade facilitation on cross-border e-commerce transactions by taking cross-border e-commerce transactions between China and the countries along the "Belt and Road" as the research object. Based on this model, we use panel data to examine the differences in the impact of trade facilitation measures on cross-border e-commerce transactions in terms of infrastructure, customs clearance environment, government–governance capacity, and cross-border logistics services on the scale of cross-border e-commerce transactions in the countries along the "Belt and Road".

2. Literature Review

In domestic and international academic circles, trade facilitation, cross-border e-commerce transactions, trade scale and other research themes have been fruitful areas of study in recent years; however, the results of exploring the impact of trade facilitation environment on the scale of cross-border e-commerce transactions are very limited. The existing studies, mainly along the lines of trade facilitation and the construction of its indicator system, the impact of trade facilitation on trade scale, etc., gradually deepen and unfold [2].

2.1. Review on the Connotation and Evaluation of Trade Facilitation

Trade facilitation connotes the enhancement and improvement of trade effects through the simplification of trade procedures and formalities, harmonization of applicable laws and regulations, and standardization and improvement of infrastructure, i.e., by preventing and controlling trade risks and reducing trade costs [3]. The OECD estimates that for every 1% reduction in trade costs, trade can increase by USD 40 billion. Regarding the measurement of trade facilitation indicators, traditional studies focus on the simplification and harmonization of international trade procedures, i.e., the reduction of trade costs that occur at the "border", mainly related to the transparency of the rules of the customs control system, customs clearance efficiency, tariff system, etc. The contemporary trade facilitation, on the other hand, extends from "at the border" to "within the border", i.e., the main content adds logistics infrastructure, communication facilities, logistics performance, government governance capacity, and related service measures to the traditional trade facilitation [4]. At present, the WTO, APEC and the World Bank have introduced different indicator systems for evaluating and measuring trade facilitation. Since the evaluation system of trade facilitation indicators is more complex and the evaluation of its measurement is not unified in academic circles, the authors believe that before carrying out this study, it is necessary to combine the research subjects and make a scientific assessment of the trade facilitation evaluation system [5].

2.2. Review of Research on the Impact of Trade Facilitation on Cross-Border E-Commerce Transactions

Combing domestic and foreign research results, the research on trade facilitation can be divided into two major aspects: first, the analysis of the impact of trade facilitation on cross-border e-commerce transactions. Essentially, trade facilitation is the reduction of transaction costs through "institutional arrangements" involving multiple fields, which in turn generates trade creation and trade expansion effects, promotes the development of international trade, and further enhances the overall welfare of society [6,7]. Second, in terms of research methodology, the Global Trade Analysis Model (GTAP) and Computable General Equilibrium Model (CGE) are usually used to analyze and verify the effects of enhancing trade facilitation on trade flows, trade costs, e-commerce, capital investment, business opportunities, etc. Existing results carry out research on its contribution to trade growth from different perspectives, such as facilitation of customs clearance procedures, infrastructure construction standards, non-tariff barriers, port operation efficiency, domestic environmental regulations, and construction of free trade zones, laying an important foundation for the study in this paper [8,9].

In summary, there is a great deal of literature on the impact of trade facilitation on cross-border e-commerce transactions, which provides important theoretical and factual basis for this study; however, results on cross-border e-commerce trade effects as the main body of research are not very common, and there is still the possibility of further in-depth excavation and expansion in the research content and research methods. Specifically, the construction of the evaluation system of trade facilitation first needs to be improved in terms of relevance. Second, the research subject is not micro-specific enough, and results of research on the impact of the scale effects of cross-border e-commerce trade are relatively rare. Third, the design of the research structure is not sufficiently considered, and the perspective is singular, without a comprehensive analysis of the impact and constraints from the perspective of differences in trade facilitation in bilateral trade countries.

In view of this, the present paper intends to first, carry out the design of a trade facilitation evaluation index system for bilateral countries based on transaction cost theory; second, construct a conceptual model of the impact of trade facilitation environment on cross-border e-commerce transactions; and third, use a dynamic panel model with interaction terms to verify the effects of trade facilitation measures such as cross-border transportation costs, cross-border customs clearance costs, political transaction costs and time costs on cross-border e-commerce trade Finally, the effects of trade facilitation measures such as cross-border transportation costs, cross-border customs clearance costs, political transaction costs and time costs on the scale of cross-border e-commerce trade will be further verified using the dynamic panel model to further explore the extent of the role of government–governance capacity on the customs clearance environment in the process of cross-border e-commerce transactions [10,11].

3. Construction of a Conceptual Model of the Impact of Trade Facilitation Based on Cross-Border Logistics Costs on the Scale Effect of Cross-Border E-Commerce Trade

In the fields of new institutional economics and trade economy, transaction costs are usually interpreted as economic exchange costs, which can be broken down into two parts, "transaction" and "cost" [12]. Transaction refers to "the conversion of ownership of goods between individuals"; correspondingly, transaction costs are understood as the costs incurred by both parties to establish a relationship. Williamson believes that transaction costs are all the resources needed to negotiate, obtain business information, and execute contracts; that is, they include manager transaction costs incurred in the exercise of power within the company, market transaction costs incurred in the external market of the company, and operation and maintenance Political transaction costs incurred by the government's institutional framework can also be included. Although cross-border e-commerce is a new mode of international trade, transaction costs represented by cross-border logistics occupy an important position. Compared with traditional trade, the biggest advantage of cross-border e-commerce transactions lies in the saving of transaction costs, that is to say, the cost of information flow between the two parties in terms of business information acquisition, sharing, and exchange has been greatly reduced. However, cross-border e-commerce transactions are often sporadic and small items and groceries are mainly purchased in the form of daily consumer goods transactions; thus, higher requirements are often placed on the flow of goods. [13,14] In this case, the cross-border logistics cost of related goods in cross-border e-commerce business is directly related to the logistics infrastructure, customs environment, and government–governance contexts of bilateral trade countries. These will directly affect the confidence of cross-border e-commerce traders and the scale of transactions via such paths as transport costs, time costs, political transaction costs and information costs [15,16].

In this way, information flow and capital flow for cross-border e-commerce transactions can be completed online, and their impact on transaction costs is relatively weakened, while logistics needs to be realized offline, and has become the bottleneck that restricts the trade cost of cross-border e-commerce transactions. Logistics costs include a wide range of content. According to the practical needs of cross-border e-commerce transactions, this article mainly discusses transportation costs, customs clearance costs, government–governance costs, and time costs.

3.1. Analysis of Infrastructure Impact Based on Cross-Border Transportation Costs

The cross-border transportation cost usually involves all the expenses for completing the transportation within a certain period of time. In cross-border e-commerce logistics, this cost is closely related to the quality of the national logistics infrastructure of both parties to the transaction [17]. Infrastructure refers to the quality and service capabilities of domestic and foreign ports and port infrastructure. Generally, it can be divided into two aspects: hardware and software infrastructure services in international trade, usually including the quality of seaports, airports, roads, railways and other infrastructures, and the capacity of loading and unloading and transshipment of transportation services. In practice, infrastructure is mainly reflected through facility quality, and facility quality as a qualitative concept can be quantified through a series of indicators [18].

Taking Khorgos port in Xinjiang as an example, as an important transportation node between China and Central Asian countries, the state has issued a series of supporting development policies for this port in recent years. With the improvement of logistics facilities, the efficiency of port functions has been rapidly improved, greatly enhancing the port's competitive advantage in cross-border trade and international transportation. With the increase in the number of China–Europe express trains, the volume of customs clearance trade has increased year by year (see Table 1).

Table 1. Statistics on the customs clearance trade volume at Khorgos port and the number of China–Europe trains opened from 2011 to 2019.

Time	2011	2012	2013	2014	2015	2016	2017	2018	2019
Customs clearance trade volume (US$ billion)	71	110	144	146	120	240	386	498	–
Number of China–Europe Class Trains Opened	17	42	80	308	815	1702	3673	6300	8225

For cross-border e-commerce transactions, the quality of infrastructure plays a more important role in the transfer of cargoes between the two sides; better logistics infrastructure in the bilateral trading countries results in stronger operational capacity, higher operational efficiency [19], higher quality of logistics services provided in the transaction process, and accordingly lower transportation costs, which help improve the overall quality and scale of a country's cross-border e-commerce transactions and realize the positive impact of the scale of cross-border e-commerce transactions [20]. Accordingly, this paper proposes hypothesis 1 as follows.

Hypothesis 1 (H1). *Infrastructure development in countries along the route ("along the route" refers to the countries along the "Belt and Road", the same below.) has a positive effect on the scale of cross-border e-commerce by saving cross-border transportation costs.*

3.2. Analysis of the Impact of Customs Clearance Condition Based on the Cost of Cross-Border Customs Clearance

Cross-border customs clearance is one of the necessary aspects of international trade activities, and all inbound and outbound goods must enter into circulation under customs supervision within a specified period and at a specified location [21,22]. The customs clearance environment is mainly an assessment of the customs regulatory environment, which is closely related to customs supervision and clearance management as well as commodity inspection, quarantine, and the origin regulatory environment, including specifically the complexity and transparency of customs clearance procedures management, the number of export documents, turnaround time, etc. Since the establishment of the first batch of cross-border e-commerce pilot zones in China in 2015, a total of 105 zones have been established in five batches, aiming to reduce the costs of logistics and customs clearance for cross-border e-commerce transactions in all aspects and to promote the experience and policies of cross-border e-commerce transactions. With innovative regulatory measures such as "advance declaration, goods inspection and release, simplified declaration, clearance and release, summary statistics", the scale of cross-border e-commerce transactions has been promoted [23,24]. According to Guangzhou Customs data, in the first four months of 2020 alone, the total import and export commodities supervised through the cross-border e-commerce management platform in the customs area was RMB 11.8 billion, an increase of 7% over the same period last year and accounting for 22.6% of the country.

In practical business, the quality of the environment of customs control in bilateral countries has a direct impact on e-commerce transactions, and the optimization of the customs control environment depends on the administrative control of both sides, i.e., on the preference for a transparent regulatory system and trade approval procedures. Therefore, it is very important to correctly assess the effectiveness of import and export procedures, the transparency of border management, the average number of days for customs clearance, the number of major document types and other import and export process efficiencies. In summary, the quality of the customs clearance environment will have a significant impact on the cross-border e-commerce trade effect. Therefore, this article proposes hypothesis 2, as follows.

Hypothesis 2 (H2). *The cross-border customs clearance environment of coastal countries positively affects the scale of cross-border e-commerce by reducing the cost of cross-border customs clearance.*

3.3. Analysis of the Impact of Government–Governance Capacity in Importing Countries Based on Political Transaction Costs

Political transaction cost refers to the various resources consumed in the exchange of rights in the political sphere; such costs often arise due to information asymmetry, opportunism and asset specificity. Because the two sides in cross-border e-commerce transactions are located in countries with different political and institutional environments, the two sides of the transaction can easily generate asymmetric information and subsequently incur political transaction costs [25]. At this point, the government–governance environment of bilateral countries plays an important role in influencing the political transaction costs [26,27]. A good government–governance environment can introduce adaptive institutional policies, which can better maintain the order of national market operations, and helps domestic manufacturers to reduce production costs and transaction costs so that their products can have a competitive advantage in the international market competition and promote the development of national trade [28,29].

Government–governance capacity is also reflected in the control of corruption, and there is an important correlation between the level of government corruption and a country's foreign trade and economic situation [30]. It has been shown that in some less developed countries, unscrupulous businessmen influence the formulation and implementation of policy measures and even laws by, for example, bribing government officials. The deeper the level of corruption, the more likely it is that trade intervention will occur to protect and facilitate those who pay bribes [31]. In countries with a higher degree of democracy, government administration is often widely monitored and constrained by the public, and thus policy formulation, laws and regulations are relatively open and transparent. This environment is more conducive to trade liberalization and trade openness, which helps the implementation of liberal policies, thus making a country's trade environment more open [32,33].

In addition, according to classical free trade theory and institutional economics transaction cost theory, a more fair, transparent and open trading environment is conducive to the development of bilateral trade. Therefore, the effectiveness, transparency and reliability of trade policies and regulations of bilateral trade between countries can provide facilitation and support for trade promotion, and ensure the reduction of uncertainties in a country's customs clearance environment. Therefore, government–governance environment itself has a positive impact on the scale of cross-border e-commerce transactions while at the same time indirectly promoting the scale of cross-border e-commerce transactions through the continuous influence and improvement of the customs clearance environment. Therefore, this article proposes hypotheses H3a and H3b, as follows.

Hypothesis 3a (H3a). *The government–governance capabilities of countries along the route promote the expansion of cross-border e-commerce trade by saving political transaction costs.*

Hypothesis 3b (H3b). *The governance capacity of the countries along the route promotes the impact of customs clearance on the scale of cross-border e-commerce.*

3.4. Analysis of the Impact of Cross-Border Logistics Services Based on Time Costs

In transaction cost theory, time cost refers to the time that customers must spend to get the desired goods or services, converted into a cost; this cost may be the time cost of reaching an agreement, and may also be the transaction process due to the handover conversion inefficiency brought about by waiting, or caused by missed market opportunities. According to Khorgos Customs statistics, the average whole train changeover time of inbound and outbound China–Europe trains at Khorgos port has been reduced from an average of 6 h in 2017 to about 3.5 h now. In addition, the inbound and outbound China–Europe trains via Khorgos railroad port in 2019 amounted to 3403 trains, an increase of 65.60% year-on-year, with a freight volume of 3,135,100 tons, an increase of 71.86% year over year. For the January–May 2020 period, outbound China–Europe trains increased by 28.95% year over year, driving the cumulative export of cross-border e-commerce parcels at Alashankou Port to exceed 10 million pieces during the same period.

As can be seen, for cross-border e-commerce merchants it is very important to complete the delivery of high-value goods in a timely manner in order to minimize inventory backlog and improve circulation efficiency in order to ensure corporate cash flow and give full play to comparative cost advantages. For time costs, which are often hidden, they need to be evaluated in combination with order elapsed time, stock preparation time, shipment cycle and delivery time to customers. The essence of efficient cross-border e-commerce transactions in terms of time lies in the use of synchronized online and offline operations; however, if the exchange of goods between customers still needs to use offline logistics to complete the actual transmission, then the time cost remains subject to cross-border logistics services. Cross-border logistics services can be analyzed from the perspective, of either capacity or efficiency [25]. For capacity, the impact of the freight sector on cross-border logistics parcel tracking queries and freight service quality is examined; efficiency, specifically logistical efficiency, is usually explained as the ratio of input to output of logistics elements within a certain period, and represents the cost and efficiency of the whole process of freight logistics [32]. Therefore, this article proposes hypothesis 4, as follows.

Hypothesis 4 (H4). *Cross-border logistics services along the route have a positive effect on the scale of cross-border e-commerce trade by saving time and costs.*

In summary, based on the four transmission paths under transaction costs, this paper constructs a conceptual model of the impact of trade facilitation environmental factors on the scale of cross-border e-commerce transactions represented by infrastructure, customs clearance environment, government–governance capabilities, and cross-border logistics services, and intends to introduce the interaction terms between government–governance capabilities and customs clearance environment into the model in order to verify the possible differences in the impact of different trade facilitation measures on the scale of cross-border e-commerce transactions (see Figure 2).

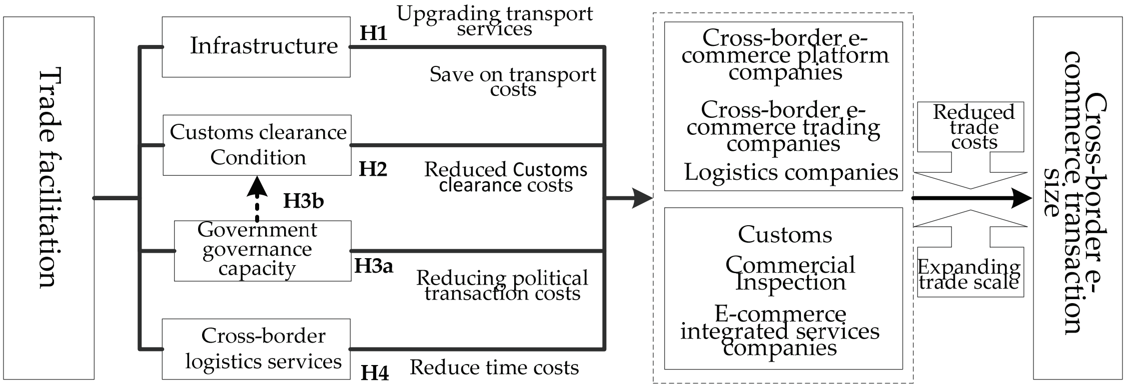

Figure 2. A path analysis framework for the impact of trade facilitation on the scale effect of cross-border e-commerce.

4. Models and Data

4.1. Variable Selection and Data Source Description

4.1.1. Explained Variables

This paper selects the trading partner countries along the "Belt and Road" with which China conducted cross-border e-commerce transactions between 2013 and 2019 (The sample period is set at 2013–2019 for two main reasons: first, data availability; second, this period coincides with the transition of China's cross-border e-commerce transactions from the growth phase to the maturity phase)as the sample countries (The sample countries are selected as the main destination countries of China's export cross-border e-commerce in the 2020 "B2C Cross-border E-commerce Platform Overseas Research Report", including: Russia, France, the United Kingdom, Brazil, Canada, Germany, Japan, South Korea, India, Thailand, Malaysia, Singapore, Indonesia, Kuwait, the UAE, Qatar and other 16 countries), and conducts a study on the impact of trade facilitation on the trade effect of cross-border e-commerce.

4.1.2. Explanatory Variables

Trade facilitation level indicators are the core explanatory variables in this paper. For the measurement of trade facilitation environment, this paper relies on the trade assessment system proposed by Wilson in 2003 based on four aspects of trade facilitation in each partner country, namely infrastructure, customs clearance environment, government–governance environment and cross-border logistics service capacity. The specific index selections and correspondences are shown in Table A1.

In addition, this article selects the number of postal international express orders (PIE), cross-border Internet payments (CBP), per capita GDP of trading partner countries (GDPE), broadband Internet users (ITP), etc., (Source of data for control variables: World Bank Database) as control variables in order to carry out empirical verification and analysis.

4.2. Econometric Model Construction

Based on transaction cost theory in combination with the previous analysis, it can be seen that the impact of trade facilitation environment on cross-border e-commerce transactions unfolds through different transmission paths. To ensure the conciseness of the empirical analysis process, this paper first uses principal component analysis to calculate the quantitative values of each path, such as infrastructure, customs clearance environment, government–governance environment, and cross-border logistics service capacity, and then uses them as explanatory variables in the model regression. Before the model regression, all variables are taken as natural logarithms to effectively reduce the heteroskedasticity of the model. Considering that the growth of cross-border e-commerce transaction scale has a certain time continuity, i.e., the current period's cross-border e-commerce transaction scale is influenced by that of the previous period, and considering the endogeneity problem caused by the possible omission of variables, the lagged period of the explained variables is introduced as an explanatory variable in the model, i.e., the dynamic panel data econometric regression model (Equation (1)) is constructed as follows:

$$\begin{aligned} LnTrade_{it} &= \alpha_0 + \rho LnTrade_{it-1} + \beta_1 LnLF_{it} + \beta_2 LnCE_{it} + \beta_3 LnGE_{it} \\ &\quad + \beta_4 LnLS_{it} + X_{it} + \varepsilon_{it} \\ X_{it} &= \theta_1 LnPIE + \theta_2 LnCBP + \theta_3 LnGDPE_{it} + \theta_4 LnITP_{it} \end{aligned} \tag{1}$$

where the subscript i represents the country and t represents the year. *Lntrade* is the explanatory variable, indicating the scale of cross-border e-commerce transactions in each country; $Lntrade_{i,t-1}$ is the period after the explanatory variable; *LnLF*, *LnCE*, *LnGE*, and *LnLE* represent the level of infrastructure, customs clearance environment, government governance capacity, and cross-border logistics service capacity, respectively; X is the control variable; and ε is the random error term, which varies simultaneously with time and individuals.

Equation (1) is the base regression model of this paper, taking into account that trade facilitation is one of the multiple factors that promote the effect of cross-border e-commerce trade, and the existing trade facilitation evaluation measurement data are subjective data, which cannot measure absolute amounts in the same way as factual data; in order to better verify the relationship between them, it is therefore appropriate to use the amount of change to measure the analysis at the same time, in order to eliminate the individual effects in the model and to alleviate the effects of multicollinearity between the explanatory variables both in Equation (1) (This article first standardizes the indicators under the five paths, and then uses the principal component analysis method to select the first two principal components that cumulatively explain 60% or more of the change in the above difference to perform a weighted average so as to obtain the core indicators for measuring each path. Due to space limitations, the calculation results of each principal component score and contribution rate are not provided here) and the common time trend between variables, etc. Thus, perform log differencing on Equation (1) to get regression Equation (2).

$$\Delta LnTrade_{it} = \rho LnTrade_{it-1} + \beta_1 \Delta LnLF_{it} + \beta_2 \Delta LnCE_{it} + \beta_3 \Delta LnGE_{it} + \beta_4 \Delta LnLS_{it} + \Delta X_{it} + \Delta\varepsilon_{it} \tag{2}$$

At the same time, in order to verify for the influence of government–governance capacity in the customs clearance environment on the scale of cross-border e-commerce transactions, the model introduces the interaction term between government–governance capacity and customs clearance environment to obtain the regression Equation (3).

$$\begin{aligned} \Delta LnTrade_{it} &= \beta_0 LnTrade_{it-1} + \beta_1 \Delta LnLF_{it} + \beta_2 \Delta LnCE_{it} + \beta_3 \Delta LnGE_{it} \\ &\quad + \beta_4 LnLS_{it} + \beta_5 \Delta LnGE_{it} \times \Delta LnCE_{it} + \Delta X_{it} + \Delta\varepsilon_{it} \end{aligned} \tag{3}$$

4.3. Estimation Method Determination

In Equation (1), the explanatory variable is lagged by one period as the explanatory variable; this model construction belongs to the typical dynamic panel model. The advantage of a dynamic panel is that it better solves the endogeneity problem that tends to exist in the traditional fixed-effects and random-effects model panel data models; however, the model is vulnerable to the interference of heteroskedasticity in the model. In order to avoid bias in the regression results, this paper proposes to adopt a two-step systematic generalized moment estimation, i.e., a systematic GMM approach, in the selection of estimation methods in order to obtain consistent and valid GMM model estimates. The model also needs to be tested for the validity of instrumental variables, i.e., the Hansen test and the correlation test of residual terms.

In addition, it should be noted that the model includes five main explanatory variables: trade facilitation indicators and their interaction terms, the first-order lags of the explanatory variables, and control variables such as cross-border Internet payments, GDP per capita, and broadband Internet users. Most of these explanatory variables are closely associated with changes in the size of a country's cross-border e-commerce transactions; see the Pearson correlation coefficient matrix in Table A2 for details.

4.4. Model Estimation and Analysis of Results

The regressions of Equations (1)–(3) were conducted using Stata15 software; the empirical results are shown in Table A3. In particular, SYS-GMM is the core analytical model used to facilitate comparison and to carry out robustness tests of the model. The estimation results of mixed OLS regression, fixed effects regression, random effects regression and differential GMM are also presented in Table A3.

Looking at the overall regression results in Table A3, the model first estimates the two key tests of validity in the systematic GMM estimation method. In particular, the p-value for the AR(2) test is 0.310, indicating that there is no second-order serial correlation in the residual terms. The p-value for the Hansen test statistic is 0.438, which is greater than the commonly set critical value of 0.05; thus, all instrumental variables are valid. The R^2 values of the regression models are 0.7466, 0.7587, 0.7707 and 0.8318 respectively, with generally low R^2 values. The main reasons for this analysis may be due first to the data of the explanatory and explained variables containing both factual and subjective data, as the simultaneous occurrence of such different types of data will likely lead to this result, and second to the trade facilitation evaluation indicators in the explanatory variables, as the human and social capital factor included in the explanatory variables is difficult to measure and quantify, and subjective evaluation data must be used as a substitute. However, with the introduction of the cross-sectional term, the R^2 value increases significantly, indicating that the explanatory power of the model has been enhanced. In terms of the regression coefficients of the control variables, the explanatory variables with a lag of one period are significantly positive and the regression coefficients are less than one, which is consistent with the actual situation and helps to ensure the overall explanatory power of the model. In addition, all three control variables also show a significant positive contribution to the growth of cross-border e-commerce transaction size, which is more in line with both the theoretical and practical situations.

From the regression results of the DIFF-GMM model, the overall quality of infrastructure, customs clearance environment, government–governance capacity, and cross-border logistics services in trade facilitation measures all have a significant positive effect on the scale of cross-border e-commerce transactions in each path, i.e., hypotheses H1, H2, H3a and H4 are all supported. Meanwhile, in the SYS-GMM regression, infrastructure, customs clearance environment and government–governance capacity show a stronger influence. This suggests that for a new trade model such as cross-border e-commerce, the smooth conduct of transactions depends first and foremost on the maturity of logistics support facilities in bilateral countries. While cross-border e-commerce transactions are growing at a rapid pace, the smooth flow of every node in the supply chain should be ensured. Secondly, cross-border e-commerce transactions also require high efficiency in customs clearance, as the efficiency and construction level of customs in terms of the time taken to clear goods, the frequency of inspection and clearance methods, and the intelligence and informatization of ports directly affect the cost of clearance for cross-border e-commerce transactions. This means that there is a need to create a more streamlined customs clearance environment and regulatory environment for cross-border e-commerce.

At present, the country is vigorously developing the construction of free trade zones and comprehensive pilot zones for cross-border e-commerce, providing a higher level, more preferential policies and a more simplified one-stop service platform for cross-border e-commerce through preferential trade arrangements in free trade zones and providing solutions and professional information support for the global supply chain by, i.e., optimizing the customs clearance environment at ports, improving the efficiency of cargo clearance and reducing the cost of customs clearance for enterprises to achieve substantial Support.

This is all premised on the improvement of the government's governance capacity, which is further evidenced by the regression results of the interaction term in the SYS-GMM model. The positive coefficient of the interaction term indicates that governance capacity not only contributes to the smooth running of cross-border e-commerce transactions on its own, but also brings about the expansion of cross-border e-commerce transactions by influencing the customs clearance environment. The stronger and more efficient the governance capacity, the more likely it is in practice to provide more preferential and transparent trade policies and convenient trade measure arrangements for importers and exporters; thus, hypothesis H3b holds and the trade promotion effect of government–governance capacity on cross-border e-commerce transactions is evident and empirically verified by the data.

It should be noted that while the coefficients of the above explanatory variables can indicate the impact of the trade promotion effect on the scale of cross-border e-commerce transactions from their respective paths and perspectives and clarify the important role of government governance capacity in the impact path, they have not yet been explored in terms of the total impact of this trade facilitation condition on cross-border e-commerce transactions. To this end, this paper will further examine the overall impact by specifically examining the impact government–governance capacity on the scale of cross-border e-commerce transactions by calculating the value of the bias effect in the model. According to Equation (3) in this paper, the partial derivative can be obtained from the bias effect Equation (4), as follows:

$$\frac{\partial \Delta LnTrade_{it}}{\partial \Delta LnGE_{it}} = \beta_{3it} + \beta_5 \Delta LnCE_{it} \tag{4}$$

The partial effect of government governance capacity on the trade promotion effect of cross-border e-commerce transactions can then be calculated according to Equation (4) (In model (4), $\Delta lnCE$ is calculated using the mean of the difference variables of the logarithm of the change in customs environment for the full sample of countries, and the calculation represents a bias effect based on the mean level); from the calculation results in Table A3, it can be seen that the partial effect of government–governance capacity on the trade promotion effect of cross-border e-commerce transactions is 4.0147 ($\Delta lnCE$ uses the mean of the difference variables of the logarithm of the quantile values of the full sample, and therefore represents a bias effect at the mean level.). These calculation results indicate that government–governance capacity has a significant trade promotion effect on cross-border e-commerce transactions, and the trade promotion effect is high and very clear.

4.5. Robustness Tests

From the regression results of each econometric model in Table A3, it can be seen that although the explanatory variables have slightly different regression results and significance in each model, the significance and coefficient signs of cross-border logistics services, customs clearance environment and government–governance indicators are the same, and there are differences only in the degree of significance and coefficient size; thus, the above regression results have clear robustness. To further prove the robustness of the empirical validation conclusion, we regressed again with the relative proportion of the cross-border e-commerce export (import) transaction scale as the explanatory variable. In the regression results of the SYS-GMM model of the robustness test, there is no second-order serial autocorrelation in the AR(2) test, and the p-values of the instrumental variable validity test statistics are all higher than 5%; thus, the estimation results of the model are considered to be reasonably valid. The regression results show that although there are still slight differences in the estimated results of each explanatory variable in each model, the two indicators of infrastructure and government–governance still show high significant effects among the four trade facilitation environment indicators, which indicates that the regression results of the robustness test model with the proportion of cross-border e-commerce transaction scale as the explanatory variable also have clear robustness.

5. Conclusions and Policy Recommendations

5.1. Conclusions

In this paper, we have conducted a study on the impact of trade facilitation on the trade scale effect of cross-border e-commerce transactions, using dynamic panel data based on interaction terms around four types of trade facilitation environmental factors: logistics facilities, customs clearance environment, government–governance environment, and logistical efficiency. The research returned the following results.

First, the trade facilitation environment is constrained and influenced by four paths, transport costs, time costs, customs clearance costs and political transaction costs, which affect the expansion of a country's cross-border e-commerce transactions. Second, among the different paths and factors affecting the trade facilitation environment the impact of infrastructure quality varies greatly, which shows that the improvement of logistics infrastructure plays an important role in the expansion of cross-border e-commerce trade on both sides. This further demonstrates that China is right to give top priority to infrastructure connectivity in "Belt and Road" construction. Third, the skewed effect shows that the level of governance has significantly contributed to the improvement of the customs clearance environment and trade facilitation.

5.2. Policy Recommendations

Under the current situation of increasingly complex international supply chains, designing effective trade facilitation environment improvement measures is a realistic need to adapt to the sustainable development of cross-border e-commerce. The findings of this paper will provide a reference for the development and improvement of relevant measures to optimize the trade facilitation environment.

First, it is necessary to further accelerate the improvement of port infrastructure construction and to promote the interconnection of infrastructure.

The government should continue to increase the construction and investment of domestic port infrastructure, and especially accelerate the construction of free trade zones around the region as a reference point, as well as strongly support inter-regional interconnection. Strengthening financial and technical support for the construction of ports, land and railroad infrastructure with countries in Southeast Asia and West Asia in order to realize the interconnection and interoperability of infrastructure with countries along the route is also desirable.

Second, the customs environment should be optimized, promoting customs clearance facilitation and intelligence and strengthening cross-border inter-customs cooperation.

Continuously deepening bilateral and multilateral customs clearance cooperation under the leadership of the government and strengthening docking and customs clearance rules with ASEAN countries and countries along "The Belt and Road" through the construction of cross-border e-commerce pilot zones and free trade zones will further accelerate the construction of the port management sharing platform and improve the intelligence of port management.

Third, on the basis of the existing government administrative management advantages, improving governance capacity will contribute to the excellence of the trade environment.

On the one hand, the government should take advantage of current administration to comprehensively strengthen the combining of global supply chains, cut administrative intervention in trade policies, and appropriately reduce and decentralize power, while at the same time resolutely resisting corruption in order to create service-efficient governance. On the other hand, through an appropriately relaxed foreign exchange control policy, the government should relax the management of the virtual accounts of foreign payment institutions for cross-border e-commerce and simplify filing, account opening and reporting, etc., as reducing the complexity of these procedures and processes facilitates the operation of enterprise funds.

5.3. Research Limitations and Prospects

Based on the analysis of trade costs, this article takes countries along the "Belt and Road" as the main body and cross-border e-commerce transactions between China and the countries along the route as the core in exploring the influence path of trade facilitation measures in the expansion of the scale of cross-border e-commerce transactions between China and countries along the route and drawing preliminary research conclusions. The findings of the study have laid an important theoretical foundation for the study of the trade expansion effects of trade facilitation, trade costs, etc., and the scale of cross-border e-commerce transactions. On the basis of this paper, subsequent studies can be considered which will go deeper and expand on the following two aspects. First, the analysis of the impact of government capacity on the influence mechanism of cross-border e-commerce trade expansion can be deepened. This study has analysed and verified the mechanism of the role and influence effect of government–governance capacity; however, there is no specific node at which the government's ability to govern plays an effective role. In the future, if the data are available, a similar analysis and validation can be carried out by expanding the sample of countries. It would also be worthwhile to explore the direction of the differential economic development level of the target countries.

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Appendix A

Table A1. Description of indicators for each explanatory variable.

Type of Indicator	Tier 1 Indicator Name	Tier 2 Indicator Name	Explanation of Indicators	Data Sources
Explanatory variables	–	Cross-border e-commerce transaction size	Import and export transactions	Net Energy's Cross Border E-Commerce Research Centre Database
Cross-border transport costs	H1: Infrastructure (LF)	Freight terminal throughput	TEU (number of TEUs)	EPS database
		Quality of infrastructure	1–5 (1 = low, 5 = high)	EPS database
		National highway infrastructure construction along the Belt and Road	1–7 (1 = low, 7 = high)	WEF_Global Compet
Cross-border customs clearance costs	H2: Customs clearance environment (CE)	Burden of customs procedures	1–7 (1 = low, 7 = high)	WEF_Global Competitiveness Report
		Cargo turnaround time	Number of days	EPS database
		Number of export documents	Number	EPS database
		Average time for customs clearance of exports	Number of days	EPS database

Table A1. *Cont.*

Type of Indicator	Tier 1 Indicator Name	Tier 2 Indicator Name	Explanation of Indicators	Data Sources
Political transaction costs	H3a: Government–governance capacity (GE)	The burden of government regulations	1–7 (1 = low, 7 = high)	WEF_Global Competitiveness Report
		Government policy transparency	1–7 (1 = low, 7 = high)	WEF_Global Competitiveness Report
		Incidence of bribery	Account for at least one bribe payment request experienced by the company (%)	EPS database
Time costs	H4: Cross-border logistics services (LS)	Cross-border logistics tracking query Cargo capacity	1–5 (1 = low, 5 = high)	EPS database
		Cross-border logistics services Capacity and quality	1–5 (1 = low, 5 = high)	EPS database
		The frequency of cross-border transportation of goods at the scheduled time to reach the consignee	1–5 (1 = low, 5 = high)	EPS database
Control variable	–	Cross-border internet payment volume	RMB billion	Statistics of China Payment and Clearing Association and "Research Report on Third-Party Cross-border Payment Industry"
	–	Number of postal international express orders	Number of pieces	Universal Postal Union Postal statistics
	–	Internet users	Number of people	World Bank Datebase
	–	GDP per capita	US$ million	World Bank Datebase

Table A2. Correlation coefficient matrix of independent variables.

	LnLF	*LnCE*	*LnGE*	*LnLS*	*LnPIE*	*LnCBP*	*LnGDPE*	*LnITP*
LnLF	1.000							
LnCE	0.404 **	1.000						
LnGE	0.358 *	0.865 **	1.000					
LnLS	0.425 **	0.620 *	0.183 *	1.000				
LnPIE	0.782 *	0.341 ***	−0.298 *	−0.185 **	1.000			
LnCBP	−0.595 *	−0.356 **	−0.387 **	−0.457 *	−0.158 **	1.000		
LnGDPE	0.575 ***	0.609 **	0.398 ***	0.308 *	0.236 **	−0.288 *	1.000	
LnITP	0.386 ***	0.277 *	0.262 *	0.669 **	−0.209 *	−0.335 **	0.304 *	1.000

Note: *, **, *** denote significant at the 10%, 5%, and 1% significance levels; the correlation calculation includes data from all 16 sample countries from 2013 to 2019.

Table A3. Model estimation results of the effect of trade facilitation on the trade effect of cross-border e-commerce.

Independent Variable	Hybrid OLS (1)	FE (2)	RE (3)	DIFF-GMM (4)	SYS-GMM (5)
L. *lnTRADE*		0.1346 **	0.1801 *	0.1524 *	0.2002 ***
				0.0017	0.0035
Δ*LnLF*	3.0211	2.9014 *	2.0357 **	2.1170 **	2.8557 *
	(−1.56)	(−2.47)	(−2.78)	(−2.06)	(1.95)
Δ*LnCE*	−1.9014 *	−0.2241 **	−0.1897 *	−0.2041 *	−2.3507 ***
	(2.37)	(1.98)	(2.47)	(2.06)	(-2.17)
Δ*LnGE*	2.0109 *	2.3056 **	0.5874 **	0.7013 ***	2.3058 ***
	(−2.14)	(−2.36)	(2.45)	(1.96)	(−2.03)

Table A3. *Cont.*

Independent Variable	Hybrid OLS (1)	FE (2)	RE (3)	DIFF-GMM (4)	SYS-GMM (5)
$\Delta LnLS$	0.1851 **	2.2381 **	2.2307 *	2.2001 *	0.1943 ***
	(5.99)	(2.69)	(2.03)	(2.51)	(0.96)
C	0.1874	0.1667	0.1790	0.5774 **	0.9730 **
	(3.23)	(4.46)	(3.81)	(−1.88)	(2.30)
$\Delta LnPIE$	0.1670 *	0.9311 *	0.705 *	0.3931 **	0.2784 ***
	(0.43)	(2.56)	(1.96)	(2.37)	(2.59)
$\Delta LnCBP$	0.1868	0.9041	0.7780 *	0.5033 **	0.1859 ***
	(0.86)	(1.99)	(1.87)	(1.09)	(2.38)
$\Delta LnGDPE$	0.4104	0.1752	0.1492 *	0.1998 **	0.0307 ***
	(−1.87)	(−1.98)	(0.57)	(0.68)	(−2.08)
$\Delta LnITP$	1.5807	1.2098	1.2049	1.4507 *	1.3368 *
	(−0.91)	(−1.47)	(−2.05)	(−2.06)	(−2.87)
t	−0.0004	−0.0006	−0.0004	−0.0001	−0.0005
	(−2.22)	(−2.38)	(−2.51)	(−0.96)	(−0.08)
Constant term	12.0328	15.523 *	17.3667 *	10.0014 **	12.3640 **
	(3.38)	(5.64)	(−4.02)	(−1.88)	(5.21)
R^2	0.4947	0.7466	0.7587	0.7707	0.8318
F/Wald	187.43	160.29	(1.333	601.75	799.80
(P)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
AR(1) test		0.0000	0.0000	0.0000	0.0000
AR(2) test		0.404	0.436	0.598	0.293
Hansan test		0.368	0.401	0.398	0.438
Observed values	1344	1344	1344	1232	1232
$\Delta LnGEit$ bias effect					4.0147

Note: *, **, *** denote significance at the 10%, 5%, and 1% significance levels, respectively, and the values in parentheses are the t-statistics of the corresponding estimates; "C" is the crossover term, C = $\Delta LnCE \times \Delta LnGE$; FE is estimated using the clustering robust standard error method, and DIFF-GMM and SYS-GMM are estimated using the two-step robust standard error method; The DIFF-GMM and SYS-GMM differential equations include the first-order lags of the explanatory variables and the first- to third-order lags of all explanatory variables as instrumental variables, respectively, the level equation of SYS-GMM introduces the first-order differences of all explanatory variables as instrumental variables, and the Collapse function is used to control the instrumental variables to avoid biasing the estimation results due to too many instrumental variables; Regarding the treatment of missing values in the sample, this paper uses the mean values of the previous and subsequent years as data to add to the dataset.

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Impact of Ports' Diversification-Driven Industrial Transformation on Operating Performance: Regulatory Effect of Port Cities' Urban Economic Development Level

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Abstract: Diversification-driven industrial transformation (DIT) has become a strategy for port enterprises dealing with the dual impacts of slowing economic growth and pressure from domestic competitors. Considering the interactive relationship between ports and port cities, the subjects of this study were publicly listed port-related enterprises in China and corresponding port cities. The main and regulatory effects were used to test and analyze the impact of port enterprises' DIT and port cities' urban economic development (UED) level on three aspects of enterprises' operating performance: profitability, operating capacity, and development capability. The study found that the relationship between DIT and operating capacity is nonlinear and shaped like an inverted U, and exhibits an increasing negative impact on profitability and development capability. The UED level promotes those two aspects of port enterprises, has minimal impact on operating capacity, and has a positive regulatory effect on the relationship between port enterprises' DIT and operating performance. The empirical test results can provide decision-making basis for port enterprises to formulate diversified transformation strategy reasonably and achieve performance improvement, which is conducive to promoting the interactive development and integration of port city in China.

Keywords: urban economic development level; port enterprises; industrial transformation; operating performance; regulatory effect

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1. Introduction

Guided by the country's "Great Maritime Power" strategy and "Belt and Road Initiative", China's ports and maritime shipping play an important role as the main carriers of trade goods. However, a combination of factors—sustained slowing of global economic growth, the spread of trade protectionism, a long-term downturn in international shipping, and negative growth of China's imports and exports—have caused the country's port industry to exhibit overcapacity, resource mismatch, and lag in core competitiveness [1]. Some Chinese port enterprises have chosen diversification-driven industrial transformation (DIT) to deal with the impact of these unfavorable factors, and have scored some initial success. For example, at this stage, Shanghai Port has formed a port logistics industry chain, including terminal loading and unloading, warehousing and storage, shipping, land transportation, and agency services. Many port companies such as Qingdao Port, Tangshan Port and Lianyungang Port have successfully transformed into the multimodal logistics industry while planting the main business of the terminal. Over time, enterprises in the port industry have arrived at the consensus that it is necessary to transform and upgrade their industrial structure and achieve sustainable development.

The development of a port is closely related to the economy of its hinterland, while the urban economic development (UED) model and level of the corresponding port city can generate substantial transportation demand for the port [2]. Clark et al. [3] found that ports are key to creating comparative advantage in their hinterland cities. According to the location theory, efficient ports bring good market and economic benefits to the city by helping its location sustainability [4]. The transport connection between ports helps to improve port service efficiency and limit distance impedance, which has a significant promoting effect on port hinterland economy [5]. The relationship between a port and its port city changes between early and mature stages of development: the port and port-oriented industries are the original development foci that drive the economic development of the port city; subsequently, the port city becomes the focus, with the transformation of its urban industrial structure driving the port's economic transformation. Interactive development and integration of a port and its port city have since become the development paradigm for modern ports and port cities. The latter's UED level, policy mechanisms, and business environment provide development support for and affect the future development direction of the former.

Ports play an important role in the global supply chain through efficient logistics operations, and each port enterprise aims to increase economic value added through its unique competitive advantage [6]. Especially under the pressure of global competition, port authorities are looking for ways to improve their operational performance, which is an important indicator of the effectiveness of the activities the enterprises perform [7]. Scholars have conducted extensive research on the impact of DIT strategies on business performance, but have arrived at dissimilar conclusions. This indicates that there is a complex relationship between a port's DIT and its operating performance. Studies on port–port city relationships have proven that coordination between the two entities is conducive to achieving positive outcomes for both. However, to date, few scholars have analyzed the impact of port enterprises' DIT on their operating performance from the perspective of port–port city relationships. As an important external environmental factor, the UED level of port cities can provide essential synergy for port enterprises that implement DIT strategies to improve performance.

After taking into consideration the data acquisition process and interactive relationship between ports and port cities, China's listed port-related enterprises and their corresponding port cities were selected as the research subjects. The aim was to examine the relationship between the port cities' UED level, ports' DIT, and port enterprises' operating performance from the perspective of external regulation and internal transformation. The research results confirmed that the UED level of the port city plays a supporting role in the process of port enterprises implementing DIT, and helps improve these enterprises' operating performance. Empirical test results can help port enterprises comprehensively consider their internal operating characteristics and external economic environment. This will aid their decision-making regarding the rational formulation of DIT strategies to improve performance, which in turn will support the interactive development and integration of China's ports and port cities.

The division of this paper is as follows. In Section 2, we make theoretical analysis and research hypotheses on the relationship between port enterprises' DIT and business performance, and the moderating effect of port cities' UED on the relationship. Section 3 is the research design, which mainly introduces the data source, variable measurement and model construction. Then, the results of the empirical test on the panel data of China's listed port enterprises are presented in Section 4, followed by the conclusions and discussion in Section 5.

2. Literature Review and Research Hypotheses

The main DIT-related theories include the resource-based, industrial organization, principal agent, transaction cost, institutional, and internal capital market theories. After taking into account the attributes of state-owned enterprises, which port enterprises are, and the characteristics of asset-heavy industries, we selected the resource-based theory and institutional explanation as the theoretical supports for this study. The resource-based theory emphasizes the importance of resources in the field of strategic management [8], and proposes that an enterprise's competitive advantage is derived from its internal resources and its own capabilities. These resources and capabilities are unique, difficult to imitate, and non-reproducible, and they help improve an enterprise's long-term operating performance. Under the resource-based perspective, DIT involves the enterprise's strategic goal of deploying its own resources in the most efficient manner [9].

The institutional explanation of DIT is particularly applicable to countries and regions with transitional economies. It emphasizes the impact of differences in institutional background on the DIT and operating performance of enterprises [10]. In transitional economies, the market mechanism is less important than the non-market mechanism. To operate, enterprises continue to rely heavily on non-market systems, such as government intervention or social networks, to obtain important resources such as capital and human resources [11]. As such, enterprises' DIT and operating performance are affected by the external institutional environment.

Existing literature shows that the impact of DIT strategies on operating performance may produce differing outcomes. An appropriate DIT level helps enterprises to diversify business risk, stabilize earnings [12], and improve financial capabilities [13]. DIT can also optimize resource allocation, increase operating efficiency, create an internal capital market, reduce financing risks, and improve the efficiency of internal capital utilization [14,15]. These lead to economies of scale and reduction in unit output costs [16], which helps expand business scope, as well as improving competitiveness and market position [17]. However, if an enterprise's resources and management capabilities cannot provide protection long enough for its new business sectors to gain competitive advantage, then those sectors will eventually be eliminated by competition. In this scenario, the enterprise's continued DIT may generate only short-term benefits. Having too many new business sectors also diverts a substantial share of limited resources, thus weakening the operating performance of the main business. Many resources are wasted if the new business sectors are poorly managed and inefficient, which increases the enterprise's cost of shared resources and reduces the overall efficiency of its resource allocation [18]. A serious internal agency problem arises when there is a mismatch between the enterprise's level of internal governance and the capital market's efficiency of operations on one hand, and excessive investments on the other hand [19,20], thus reducing the enterprise's operating performance.

Some scholars argue that no relationship exists between an enterprise's DIT and its operating performance [21,22]. However, other research shows that the relationship between the two is either that of a discount effect [23–25], a premium effect [26–28], or a complicated situation in which the two effects alternate [29–31]. Based on the conclusions from prior research and the practical actions taken by China's port enterprises toward DIT in recent years, it is evident that DIT strategies can help those enterprises grow their business. However, after comprehensively considering the negative impacts that DIT may cause, the approach adopted in this study was to regard the impacts from different DIT-related aspects of operating performance as unlikely to be simple linear relationships.

Considering the relationship that port construction has with national socioeconomic development and the particularity of port enterprises' business operations, their performance can be measured using multiple aspects, including profitability, operating capacity, and development capability. This led to Hypothesis 1 regarding DIT's impact on different aspects of operating performance:

H_{1a}: *There is an inverted U-shaped relationship between port enterprises' DIT and profitability.*

H_{1b}: *There is an inverted U-shaped relationship between port enterprises' DIT and operating capacity.*

H_{1c}: *There is an inverted U-shaped relationship between port enterprises' DIT and development capability.*

There are many Chinese and overseas studies on the relationship between ports and port cities' UED level. Si [32] found a significant correlation between port infrastructure and port cities' economy, with infrastructure construction having a role in promoting the latter's economic development. Zhao et al. [33] pointed out that although ports are the driving force behind the economic development of port cities, the competitiveness of such cities depends more on cities' own characteristics. Cong et al. [34] examined the interaction between a port's throughput and the economic indicators of its port city, and found that the former has a positive impact on the latter's GDP, which has synchronous growth with the value added by the port's secondary industries.

Scholars have shown a dynamic linkage between a port and the development of its port city. Using a port–port city relationship measurement model, Guo et al. [35] and Guo et al. [36] classified coastal ports into three types: port-driven, port–port city interaction, and urbanization-driven. They also highlighted that the port–port city relationship undergoes dynamic developments. Akhavan [37] used Dubai as a case study for research and described the dynamic development of Dubai's port city, showing a mutually beneficial relationship between the port and the port city. The sustainable development of ports and port cities has also attracted the attention of scholars. Boulos [38] believed that the key to maintaining balanced development between ports and port cities is for cities to provide the requisite infrastructure and services for the development of ports. On this basis, a model and framework to develop port–port city integration can be constructed to support sustainable development.

Xiao et al. [39] pointed out that the expansion and modernization of ports are inseparable from the development of port cities. As port developments have important impacts on the urban environment, the port–port city relationship must be fully considered to ensure the sustainable development of both. Zhao et al. [40] built a nonlinear model for the green growth of port cities, with the basic conditions being the coordinated growth of the port city's GDP and the port's throughput capacity.

These studies demonstrate the close connection between ports and port cities, and the mutual influence of both. A port's vitality drives the port city's economic development, while a port city provides the port with strong support for development. The port is the import and export locus for the urban logistics subsystem. The port city's industrial and economic development create transportation demand for the port and induce an increase in the port's production capacity. A rational economic structure for the port and port city, as well as highly developed trade and logistics capability in the port city, increase the port's comprehensive competitiveness [41]. When the port city's industrial structure is upgraded, its consumption structure rationalized, and its resource allocation optimized, the market space for port enterprises will expand. This in turn provides port enterprises with room for trial and error during the transformation and upgrading process [42]. A port city is the closest and most essential hinterland of a port. When port enterprises face the issues of industrial upgrading and industrial transformation, their profitability, operating capacity, and development capability are largely dependent on the economic development of the corresponding port city. This is especially true for export-oriented economies.

Based on the above, Hypothesis 2 was proposed.

H_{2a}: *Port cities' UED level promotes port enterprises' profitability.*

H_{2b}: *Port cities' UED level promotes port enterprises' operating capacity.*

H_{2c}: *Port cities' UED level promotes port enterprises' development capability.*

DIT has become one of the main strategic choices for port enterprises coping with an unfavorable economic situation and industrial environment. As port cities transform and upgrade their industrial structure, port enterprises have responded with DIT, and ports have gradually evolved from performing a single function to performing multiple functions. Port cities that are highly developed economically provide associated ports with the following: a good business environment for transformation and upgrading;

increased investment in the freight collection, distribution, and transportation system, and construction of basic infrastructure; relevant policy support and adequate high-quality factors of production. These in turn drive the development of port enterprises' dependent industries, such as loading and unloading, comprehensive logistics, and port management, as well as that of the related industries of commodity trading, multimodal transportation, and financial services. As a result, there are positive interactions between a port and the port city, which enable capital, information, business, and logistics flows, creating synergies. Therefore, port cities' UED level has a role in promoting port enterprises' DIT and improving their operating performance. Based on this analysis, this study proposed Hypothesis 3.

H$_3$: *Port cities' UED level promotes port enterprises' implementation of DIT and improvement of operating performance.*

The port enterprise–city relationship and the research model of this study are illustrated in Figures 1 and 2, respectively.

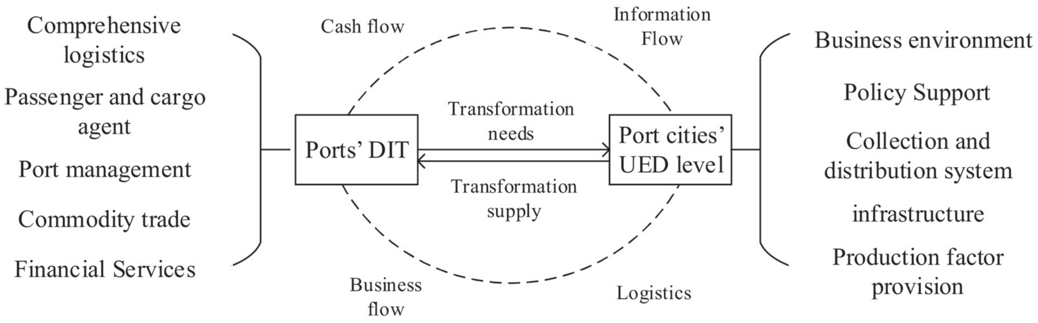

Figure 1. Port enterprise–city relationship.

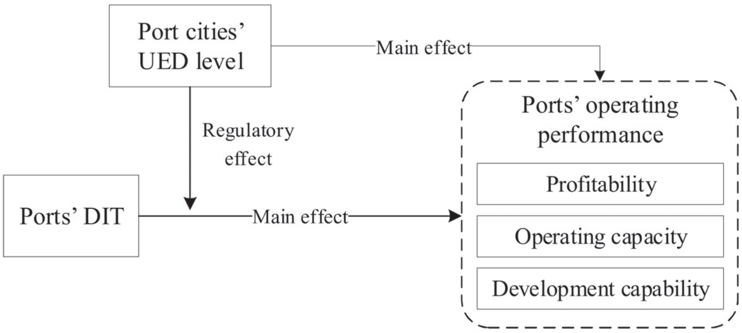

Figure 2. Research model.

3. Research Design

3.1. Sample Selection and Data Sources

With data availability as the consideration, a group of publicly listed port enterprises was selected as the research subject. There were originally 20 port enterprises in the group, but the Wanjiang Logistics Group was subsequently removed because after its subsidiary Huaikuang Logistics was suspected of financial fraud in 2014, it underwent a major asset reorganization during the latter part of the study period and was renamed the Huaihe Energy Group. With the alteration of the enterprise's original main business and development direction, the accuracy and reliability of the research data and results would have been compromised. With this removal, there were 19 listed port-related enterprises. Their 2012–2019 data were obtained from GTA Education Tech Ltd.'s (Shenzhen, China) CSMAR database for analysis. The data were supplemented by information from Sina Finance and the various enterprises' financial reports. With both Yantian and China Merchants Ports located in Shenzhen, the 19 listed enterprises corresponded to a total of 18 port cities. Data for the cities for 2011–2018 was mainly acquired from the EPS database, and supplemented by information from the China Economic Information Network (https://ceidata.cei.cn/, accessed on 22 March 2022) and the various cities' statistical yearbooks.

The 19 listed port-related enterprises are: (i) Yantian Port Holdings Co., Ltd. (Shenzhen, China); (ii) Zhuhai Port Holdings Group Co., Ltd. (Zhuhai, China); (iii) Beibu Gulf Port Co., Ltd. (Nanning, China); (iv) Xiamen Port Holdings Group Co., Ltd. (Xiamen, China); (v) China Merchants Port Holdings Co., Ltd. (originally Shenzhen Chiwan Wharf Holdings but renamed on Dec 26, 2018) (Shenzhen, China); (vi) Nanjing Port Group Co., Ltd. (Nanjing, China); (vii) Rizhao Port Co., Ltd. (Rizhao, China); (viii) Shanghai International Port Group Co., Ltd. (Shanghai, China); (ix) Jinzhou Port Co., Ltd. (Jinzhou, China); (x) Chongqing Gangjiu Co., Ltd. (Chongqing, China); (xi) Yingkou Port Group Co., Ltd. (Yingkou, China); (xii) Tianjin Port Group Co., Ltd. (Tianjin, China); (xiii) Tangshan Port Group Co., Ltd. (Tangshan, China); (xiv) Lianyun Port Co., Ltd. (Lianyungang, China); (xv) Ningbo Port Group Co., Ltd. (Ningbo, China); (xvi) Guangzhou Port Group Co., Ltd. (Guangzhou, China); (xvii) Qingdao Port International Co., Ltd. (Qingdao, China); (xviii) Qinhuangdao Port Co., Ltd. (Qinhuangdao, China); (xix) Dalian Port Co., Ltd. (Dalian, China).

The 18 port cities are: (i) Shenzhen, (ii) Zhuhai, (iii) Nanning, (iv) Xiamen, (v) Nanjing, (vi) Rizhao, (vii) Shanghai, (viii) Jinzhou, (ix) Chongqing, (x) Yingkou, (xi) Tianjin, (xii) Tangshan, (xiii) Lianyungang, (xiv) Ningbo, (xv) Guangzhou, (xvi) Qingdao, (xvii) Qinhuangdao, and (xviii) Dalian.

Considering the general problem of information asymmetry between enterprises and governments, and the delay in the impact of the external economic environment on enterprises' operations, there was a one-period lag in the data used for the variable of port cities' UED level.

3.2. Measurement of Variables

3.2.1. Indicators for Measurement of DIT

Presently, the most widely used indicators in China and overseas for measurement of DIT are the Herfindahl index (HI) [43,44] and entropy index (EI) [45–47]. The HI reflects the proportion of each business unit's sales to the enterprise's total sales, and is used to measure the enterprise's DIT level. It is simple and easy to calculate, and the results are scientifically valid. The disadvantage in using the HI is its inability to reflect the relatedness among the various business sectors. Unlike the HI, the EI has separability, which better measures an enterprise's related DIT and unrelated DIT. The disadvantage in using the EI is the large amount of data involved, which makes calculation complicated. Ultimately, the HI was selected to measure the DIT level of China's port enterprises in this study because when examining the post-DIT operating performance of listed port-related enterprises, it was not necessary to segregate the effects of related DIT and unrelated DIT.

The value of the HI is between 0 and 1; the larger the index value, the higher the DIT level. The equation for calculation is:

$$HI = 1 - \sum\nolimits_{i=1}^{n} {P_i}^2 \tag{1}$$

where n represents the total number of business sectors encompassed by DIT, P_i represents the proportion that each business sector's sales revenue contributes to the enterprise's total sales revenue, and HI is the Herfindahl index, with the value range being 0–1. The closer the HI is to 1, the higher the enterprise's DIT level; when the HI is 0, the enterprise's operations are confined to loading, unloading, and transloading cargo.

3.2.2. Indicators for Evaluating the UED Level of Port Cities

The relevant data were collected and organized in this study in accordance with the measurement method for level of economic development proposed by Wei et al. [48], and based on the connotations of UED. The method comprises four criteria: (i) economic scale, (ii) benefit level, (iii) economic structure, and (iv) degree of opening up. The UED level of the 18 port cities from 2011–2018 was also evaluated using the relevant data for eight indicators: (i) regional GDP, (ii) total social investments in fixed assets, (iii) GDP per capita, (iv) average wage of employees, (v) proportion of the secondary industry's output value, (vi) proportion of the tertiary industry's output value, (vii) total value of imports and exports, and (viii) actual amount of foreign capital utilized (Table 1).

Table 1. Indicator system for evaluating port cities' UED level.

Target Layer	Criterion Layer	Indicator Layer		X
		Indicator	**Unit**	
UED level	Economic scale	Regional GDP	100 million RMB	X_1
		Total social investments in fixed assets	100 million RMB	X_2
	Benefit level	GDP per capita	RMB	X_3
		Average wage of employees	RMB	X_4
	Economic structure	Proportion of the secondary industry's output value	%	X_5
		Proportion of the tertiary industry's output value	%	X_6
	Degree of opening up	Total value of imports and exports	100 million USD	X_7
		Actual amount of foreign capital utilized	100 million USD	X_8

Note: "Total value of imports and exports" is a sum of values of imports and exports.

To ensure objectivity of the comprehensive indicators for the port cities' UED level, weights were objectively assigned to the indicators using the entropy weighting method in the comprehensive evaluation by Xie et al. [49]. The weights were used to calculate the weighted sum of all the indicators to arrive at the comprehensive evaluation indicator for port cities' UED level. The steps in the calculation are stated below.

First, the original data of each indicator was subjected to dimensionless processing:

$$S_{ij} = \frac{x_{ij} - x_{min}}{x_{max} - x_{min}} \tag{2}$$

where x_{ij}, x_{min}, and x_{max} represent the original, minimum, and maximum value of an indicator, respectively. The dimensionless data were subjected to overall translation to eliminate values of zero or less, $S_{ij} = S_{ij} + \alpha$, where the value of α is 0.001.

Next, the contribution of the jth indicator to the ith port city under that indicator was calculated:

$$P_{ij} = \frac{S_{ij}}{\sum_{i=1}^{n} S_{ij}},\ i = 1,\ 2,\ \ldots,\ n \tag{3}$$

where n is the number of port cities, with the value being 18.

The entropy of the jth indicator was then calculated:

$$e_j = -\frac{1}{\ln n} \sum_{i=1}^{n} P_{ij} \ln P_{ij},\ 0 \le e_j \le 1 \tag{4}$$

The coefficient of difference of the jth indicator, $g_j = 1 - e_j$, was substituted into the equation below to ascertain the weight W_j of the various evaluation indicators. The comprehensive score for each port city's UED level was then calculated:

$$W_j = \frac{g_j}{\sum_{j=1}^{m} g_j},\ j = 1,\ 2,\ \ldots,\ m \tag{5}$$

$$S = \sum_{j=1}^{m} W_j P_{ij} \tag{6}$$

where m is the number of evaluation indicators, with the value being 8.

The average value of each indicator for the port cities from 2011 to 2018 was used for entropy weighting to ensure longitudinal and cross-sectional data comparability. After calculation, the weights corresponding to the evaluation indicators X_1–X_8 for the port cities' UED level were 0.167, 0.106, 0.050, 0.050, 0.074, 0.139, 0.200, and 0.214, respectively. In order to eliminate the influence of price factors, all kinds of monetary volume indicators were adjusted to 2010 constant prices.

Figure 3 shows the average UED levels of 18 relevant port cities from 2011 to 2018. It can be seen that the UED levels of Shanghai, Shenzhen and Tianjin are among the top three cities, corresponding to the listed port enterprises with excellent performance in Shanghai International Port Group Co., Ltd. (Shanghai, Chian), Beibu Gulf Port Co., Ltd. (Nanning, China) and Tianjin Port Group Co., Ltd. (Tianjin, China). However, Jinzhou Port Co., Ltd. (Jinzhou, China) and Yingkou Port Group Co., Ltd. (Yingkou, China), both of which belong to Liaoning Province, are located in port cities with low UED levels, and the operating performance of the two enterprises is relatively poor. According to this, it can be preliminarily inferred that the operating conditions of port enterprises may be correlated with the economic development level of the port cities where they are located.

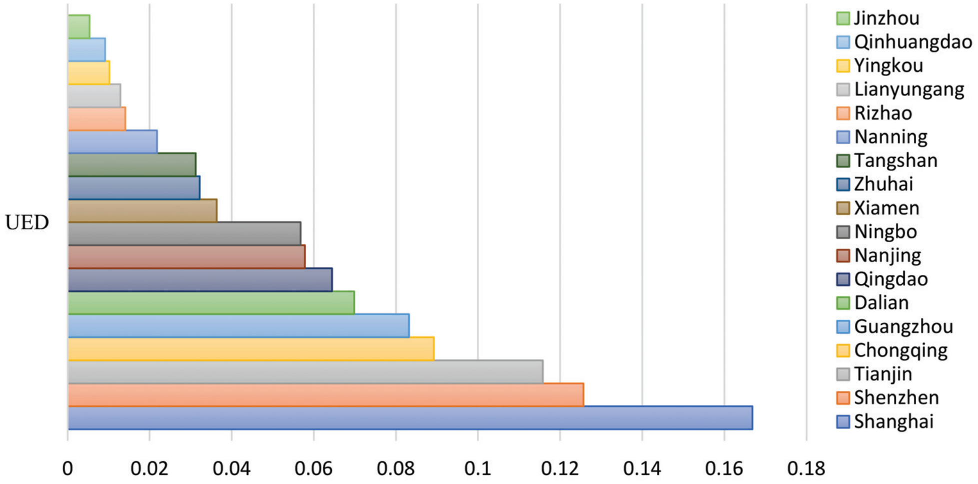

Figure 3. 2011–2018 average for port city's UED.

3.2.3. Indicators for Measuring the Operating Performance of Port Enterprises

Drawing on existing research, operating performance was set as the dependent variable, and indicators were selected from three aspects: profitability, operating capacity, and development capability. Return on total and net assets were the indicators reflecting profitability; turnover on total and net assets were for operating capacity; sustainable growth rate reflected development capability. Among them, sustainable growth rate is the maximum growth rate of the company's sales that can be achieved without issuing additional new shares and maintaining the current operating efficiency and financial policies.

3.2.4. Control Variables

In this study we controlled for the impact of the following variables on port enterprises' operating performance: enterprise size, asset–liability ratio, ratio of shares held by the largest shareholder, years of enterprise's establishment, and year effect. The definitions of and symbols for the specific variables are shown in Table 2.

3.3. Model Building

Following the hierarchical regression method for regulatory effects by Wen et al. [50] and Fang et al. [51], the indicators for the three aspects of port enterprises' operating performance were taken as the explained variables. The explanatory variables were the HI, the square term of HI, the comprehensive indicator of port cities' UED, the interaction term between HI and UED and the interaction term between the square of HI and UED. After considering the impact of the control variables, Model 1 was constructed to test Hypotheses 1, and Model 2 to test Hypothesis 2 and 3. The two models are shown using Equations (7) and (8), respectively:

$$performance_{i,t} = \beta_0 + \beta_1 hi_{i,t} + \beta_2 hi^2_{i,t} + \beta_3 asset_{i,t} + \beta_4 lev_{i,t} + \beta_5 share_{i,t} + \beta_6 age_{i,t} + year\ effect + \varepsilon_{i,t} \tag{7}$$

$$\begin{aligned} performance_{i,t} &= \beta_0 + \beta_1 hi_{i,t} + \beta_2 hi^2_{i,t} + \beta_3 ued_{i,t-1} + \beta_4 hi_{i,t} \times ued_{i,t-1} + \beta_5 hi^2_{i,t} \times ued_{i,t-1} + \beta_6 asset_{i,t} \\ &\quad + \beta_7 lev_{i,t} + \beta_8 share_{i,t} + \beta_9 age_{i,t} + year\ effect + \varepsilon_{i,t} \end{aligned} \tag{8}$$

where *performance* represents the indicators for the enterprises' operating performance, *hi* represents the DIT level, hi^2 represents the square of *hi*, *ued* represents the UED level, *i* stands for the listed port-related enterprises, and *t* stands for the year.

Table 2. List of control variables.

Type of Variable	Name of Variable	Symbol	Definition
Dependent	Return on total assets	*roa*	Net profit/Average total assets × 100%
	Return on net assets	*roe*	Net profit/Average total shareholders' equity × 100%
	Turnover of total assets	*tat*	Net operating income/Average total assets
	Turnover of net assets	*et*	Net operating income/Average shareholders' equity
	Sustainable growth rate	*sgr*	Return on net assets × Earnings retention rate/ (1 − Return on net assets × Earnings retention rate)
Independent	HI	*hi*	1 − ∑(proportion of each segment's sales revenue to the enterprise's total sales revenue)^2
Regulatory	UED	*ued*	∑(Various economic evaluation indicators × Weight from entropy calculation)
Control	Enterprise size	*asset*	Expressed by the natural logarithm of the total assets at end of period: *ln*(*ASSET*)
	Asset–liability ratio	*lev*	Total liabilities/Total assets × 100%
	Ratio of shares held by the largest shareholder	*share*	Number of shares held by the largest shareholder/Total number of shares held by the listed enterprise
	Years of establishment	*age*	Expressed by the logarithm of the years of enterprise's establishment: *ln*(*AGE* + 1)
	Year effect	*year*	Sampling years for the enterprises were 2012–2019. A total of 8 years and 7 dummy variables were included

Note: Earnings retention rate is the ratio of a company's after-tax earnings to after-tax earnings after deducting the difference between the cash dividend payable.

4. Results of Empirical Analysis

4.1. Descriptive Analysis

After analyzing the descriptive statistics, the results show that for the indicators of the sample enterprises' financial performance (return on total and net assets, turnover of total and net assets, and sustainable growth rate), the standard deviation and mean did not differ much. However, there was a large difference between the minimum and maximum values of each indicator. This shows that the profitability, operating capacity, and development capability of China's listed port-related companies are uneven at present. The port cities' UED level also varied greatly (Table 3).

The average DIT level of the sample enterprises was approximately 0.39, indicating that the overall DIT of China's listed port-related enterprises was not high. Their operations remained largely dependent on the core business of loading and unloading goods at the terminals. For the control variables, the mean of the sample enterprises' assets–liabilities ratio was approximately 40.9%, with the capital structure at a relatively safe level. The average logarithm of asset size was 23.44, and the difference between the minimum and maximum values was only 5.01. This indicates that variations in the asset size of listed port-related enterprises were not large. Separately, a test for the variance expansion factors was carried out. None of the variance expansion factors exceeded 5, indicating that there was no multicollinearity between the variables.

Table 3. Descriptive statistics of the variables.

Variable	Observed Value	Mean	Standard Deviation	Minimum Value	Maximum Value
roa	145	0.045	0.026	0.001	0.100
roe	145	0.076	0.043	0.001	0.177
tat	145	0.349	0.325	0.003	1.772
et	145	0.660	0.731	0.0429	5.300
sgr	145	0.062	0.045	−0.020	0.228
hi	145	0.385	0.237	0	0.830
ued	145	0.059	0.048	0.003	0.176
lnasset	145	23.440	1.017	20.770	25.780
lev	145	0.409	0.111	0.075	0.722
share	145	0.517	0.165	0.154	0.795
age	145	2.745	0.488	0.693	3.466

4.2. Analysis of Regression Results

In general, mixed ordinary least squares (OLS), fixed effect (FE) model and random effect (RE) model can be used to estimate the panel data model. An Lagrange multiplier test (LM test), joint hypotheses test (F test) and Hausman test were performed to determine the model form. Table 4 test results show that the RE model is more effective than the mixed OLS model and the FE model. At the same time, in order to eliminate the influence of heteroscedasticity, the feasible generalized least square method (FGLS) is selected to test the model.

Table 4. LM test, F test and Hausman test results.

Test	Statistics	*p* Value
LM test	$\text{chibar}^2 = 128.66$	0.0000
F test	F = 10.50	0.0000
Hausman test	$\text{chi}^2 = 4.29$	0.9935

In order to avoid the problem of multicollinearity, the variables involved in cross-multiplication are centralized and tested by stata15.1 software. Using *roa, roe, tat, et and sgr* as explained variables, hierarchical regression analysis is conducted on the test model. For Model 1, regression was done between port enterprises' operating performance and the Herfindahl index (HI), and the square term of the HI. For Model 2, the interactive term for (a) the HI added to the regression result in the first step as the basis and port cities' UED level and (b) the square term of the HI and port cities' UED level, were regressed to test the main and regulatory effects of the target variable, respectively. Model 1 corresponds to formula (7), and Model 2 to formula (8). The specific regression results are shown in Table 5. It is worth noting that the indicator *L.ued* indicates the lagged one-period UED level, the same below.

Model 1 tested the main effect of DIT on port enterprises' operating performance. The results show that the regression coefficients for the indicators of the sample enterprises' operating performance on the square term of the HI was significantly negative at the 1% level. The rates of turnover of total and net assets corresponding to the coefficient of the HI's first-order term were significantly positive, and the peak of the corresponding statistical model was within the range of independent variables, with the value of HI ranging from 0 to 1. This indicates that there was an inverted U-shape relationship between DIT and the port enterprises' operational capabilities. In other words, although DIT could enhance port enterprises' operational capabilities, there would be a negative effect on port enterprises' operational capabilities when the DIT level was too high and reached a particular threshold. Thus, Hypothesis H_{1b} was confirmed.

Table 5. DIT, UED level, and operating performance of port enterprises.

Variable	*roa*		*roe*		*tat*		*et*		*sgr*	
	Model 1	**Model 2**	**Model 1**	**Model 2**	**Model 1**	**Model 2**	**Model 1**	**Model 2**	**Model 1**	**Model 2**
hi	−0.009	−0.015 *	−0.023 *	−0.032 **	0.367 ***	0.419 ***	0.521 ***	0.607 ***	−0.022 *	−0.029 **
	(0.007)	(0.008)	(0.013)	(0.014)	(0.065)	(0.068)	(0.139)	(0.153)	(0.012)	(0.013)
hi^2	−0.082 ***	−0.059 **	−0.158 ***	−0.145 ***	−0.982 ***	−1.026 ***	−1.642 ***	−1.741 ***	−0.211 ***	−0.211 ***
	(0.024)	(0.025)	(0.044)	(0.049)	(0.212)	(0.208)	(0.476)	(0.496)	(0.044)	(0.046)
L.ued		0.254 ***		0.436 ***		0.778 *		1.831 *		0.339 ***
		(0.052)		(0.099)		(0.450)		(0.950)		(0.095)
hi * *L.ued*		−0.734 ***		−0.859 **		−1.097		−3.664		−0.596 *
		(0.210)		(0.382)		(1.723)		(3.814)		(0.330)
hi^2 * *L.ued*		−2.098 **		−3.035		−22.165 **		−44.071 **		−2.826
		(0.943)		(1.889)		(8.821)		(19.045)		(1.834)
lnasset	0.009 ***	0.010 ***	0.015 ***	0.014 ***	−0.034 **	−0.034 **	−0.051	−0.047	0.009 ***	0.008 **
	(0.002)	(0.002)	(0.003)	(0.003)	(0.016)	(0.016)	(0.037)	(0.041)	(0.003)	(0.003)
lev	−0.119 ***	−0.071 ***	−0.053 **	0.006	0.039	0.133	1.151 ***	1.407 ***	−0.002	0.062 **
	(0.013)	(0.016)	(0.024)	(0.032)	(0.137)	(0.139)	(0.292)	(0.311)	(0.025)	(0.031)
share	−0.005	−0.009	−0.001	−0.009	0.282 ***	0.221 **	0.466 **	0.385 *	0.046 **	0.029
	(0.011)	(0.011)	(0.020)	(0.021)	(0.090)	(0.094)	(0.198)	(0.209)	(0.019)	(0.020)
age	−0.006 *	−0.011 ***	−0.014 **	−0.027 ***	0.159 ***	0.149 ***	0.182 ***	0.200 ***	−0.011	−0.028 ***
	(0.004)	(0.004)	(0.007)	(0.008)	(0.037)	(0.039)	(0.068)	(0.077)	(0.008)	(0.009)
year	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Constant term	−0.077 *	−0.114 **	−0.181 **	−0.168 *	0.461	0.445	0.448	0.205	−0.129 *	−0.079
	(0.041)	(0.048)	(0.073)	(0.091)	(0.374)	(0.409)	(0.877)	(1.015)	(0.072)	(0.086)
Wald chi^2	224.04	274.87	91.62	121.42	52.00	83.38	38.92	55.63	59.03	77.44
Observed value	145	145	145	145	145	145	145	145	145	145

Note: *, **, and *** represent significance at the 10%, 5%, and 1% levels, respectively. The numbers stated within parentheses are the t-statistics.

The first-order coefficient of return on total assets corresponding to HI is not significant, and the first-order coefficient of return on net assets and sustainable growth rate corresponding to HI is significantly negative, indicating that the relationship between port enterprises' profitability and development capability, and their DIT level, was only reflected in the right half of the curve. Since DIT had a negative impact on the enterprises' profitability and development capability within the range of values, Hypotheses H_{1a} and H_{1c} could not be confirmed. In addition, the absolute value of the coefficients for the rate of turnover of total and net assets corresponding to hi and hi^2 was much greater than that for the rates of return on total and net assets, and sustainable growth rate. This indicates that the impact of DIT on port enterprises' operational capabilities was more significant.

In Model 2, the regression coefficients of port enterprises' rate of return on total and net assets, rate of turnover of total and net assets and sustainable growth rate to port cities' UED level were significantly positive. This indicates that port cities' UED level promoted port enterprises' profitability, operating capacity and development capability: the higher a port city's UED level, the more it improves the operating performance of port enterprises attached to it. Therefore, Hypotheses H_{2a}, H_{2b} and H_{2c} were confirmed.

After testing for the regulatory effect exerted by port cities' UED level, the results show that the interaction term between the square term of port enterprises' HI and port cities' UED level was significantly negative when total assets return, total and net assets turnover were the explanatory variables. At the same time, the coefficient of the square term of the HI was significantly negative, while the signs for the values of both were similar. Similarly, the interaction term between HI and UED was significantly negative when the explanatory variables were return on net assets and sustainable growth rate, with the same sign of the coefficient corresponding to HI. This indicates that port cities' UED level had a positive regulatory effect on the relationship between port enterprises' DIT and operating performance.

To further explain the regulatory effect, the relationship between the three aspects of port enterprises' DIT and operating performance under port cities' various UED levels were determined. As shown in Figure 4, when port cities' UED level is high, the inverted U-shaped curve between the port enterprises' DIT and operating capacity is steeper. In other words, a higher UED level strengthened the impact of port enterprises' DIT on their operating capacity. By the same principle, the UED level also had a positive regulating effect on the negative correlation between port enterprises' DIT and their profitability and development capability. Therefore, Hypothesis 3 was confirmed.

4.3. Robustness Test

On the one hand, considering that the influence of enterprise DIT on business performance may have a lag effect, this paper re-conducts model testing with explanatory variables lagging one period (Table A1), which can also solve the endogeneity problem to some extent. The regression results show that the results of this study did not change fundamentally. On the other hand, the time fixed effect model was used to replace FGLS for regression (Table A2). The aforementioned research conclusions did not vary when the estimation method was revised, and the results were consistent. Therefore, the relationship between China's listed port-related enterprises' DIT, port cities' UED level, and port enterprises' operating performance was deemed to be stable.

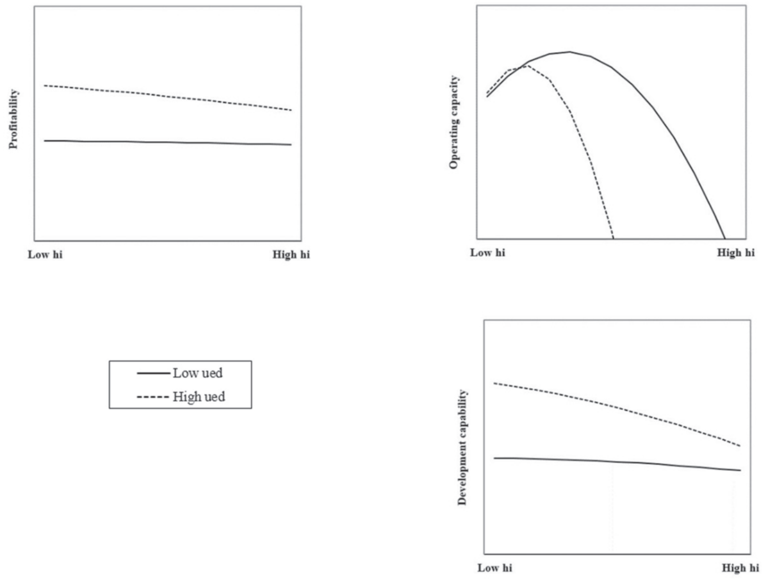

Figure 4. Regulatory effect of port cities' UED level.

5. Conclusions and Discussion

5.1. Main Conclusions and Policy Implications

In this study, the resource-based and institutional theories were used to examine the impact of port enterprises' DIT on their operating performance under the regulatory effect of port cities' UED level. The 2012–2019 data of 19 Chinese port-related listed enterprises and the 2011–2018 data of the 18 corresponding port cities were used as the basis for the corresponding empirical testing of three aspects related to the enterprises operating performance, namely profitability, operating capacity, and development capability. The test results for the main effect indicate that firstly, there was a nonlinear and inverted U-shaped relationship between port enterprises' DIT and their operating capacity. However, as DIT increases past a threshold level, it has an increasingly negative effect on profitability and development capability. This shows that an appropriate DIT level could effectively improve port enterprises' operating capacity, accelerate the rate of turnover of assets, and improve the efficiency of resource utilization.

It should be noted that for the business sectors introduced under DIT, time was required for them to mature and become profitable. During the period of analysis, the original core business of vessel loading and unloading was also affected by the overall economic situation, causing its contribution to decline significantly. This led to DIT having a negative impact on port enterprises' profitability and development capability during the initial stage of implementation: the higher the DIT level, the poorer the performance in terms of profitability and development capability.

Secondly, the conclusion after combining the test results that (a) port cities' UED level promoted port enterprises' profitability and development capability but (b) had little effect on their operating capacity, was that improvements to port enterprises' operating capacity were mainly dependent on the strategic transformation of internal businesses. This aspect was relatively less affected by the external environmental factor of port cities' UED level. However, port cities with a higher UED level would have a positive effect on port enterprises' profitability and development capability. Thus, port enterprises should harness the combined effects of an optimal level of strategic transformation of internal businesses and port cities' UED level in the ports' external environment. Doing so would enable them to improve their operating performance on the three dimensions of profitability, operating capacity, and development capability. The interactive development and integrated construction of ports and port cities would mutually complement the ports' internal transformation and the external environment to effectively improve ports' operating performance through the three aspects.

Thirdly, the test on the regulatory effect led to the conclusion that port cities' UED level had a positive regulatory effect on the relationship between port enterprises' DIT and their operating performance. Combining the conclusions of the test for the main effect, and considering the long-term effects that DIT has on profitability and development capability, port enterprises should pay extra attention to the regulatory effect exerted by port cities' UED level at the early stage of DIT. After a rational analysis of their operating results, enterprises can take effective measures to strengthen their diversified business sectors while maintaining a determined confidence in DIT. They can then achieve better profitability and potential for sustainable development through DIT and have positive interactions with the UED environment.

5.2. Limitations and Discussions

These empirical results on the one hand confirm that the impact of port enterprises' DIT on port operating performance is non-linear, rather than a single promotion or inhibition effect; on the other hand, they also show that port performance is inextricably linked to its hinterland economy. These results are of great significance for port enterprises to formulate business strategies and port cities to formulate economic policies.

Despite our efforts, there are some limitations in this study. This study may have overlooked more relevant factors, such as R&D innovation and human capital of port companies. In addition, the global economic environment is changing rapidly. There is a growing interest in sustainable production and consumption in ports, especially those in mature markets in developed regions. The sustainable development of port enterprises provides new motivation to the economic development of port cities [6]. The high energy consumption and pollution associated with port trade adversely affects the ecological environment while constraining the sustainable development of the port and its hinterland economy [52]. In order to solve this problem, the United Nations Climate Conference has proposed the "Green Port" initiative. With the advent of the fourth industrial revolution, the information industry has become the new engine driving the world's economic growth, and digital technology, while enabling green development [53], is also subtly reshaping the maritime industry and changing the way ports operate in the global transportation system. To remain competitive, ports need to actively implement port digitization and build "smart" ports [54].

Therefore, in the future, our research will pay more attention to the mechanism of green innovation, digital technology and other factors on the transformation and upgrading of port enterprises' DIT and port cities' UED, which can help the sustainable development of ports and their hinterlands.

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Appendix A

Table A1. Robustness test 1.

Variable	Model 1					Model 2				
	roa	***roe***	***tat***	***et***	***sgr***	***roa***	***roe***	***tat***	***et***	***sgr***
hi	−0.002	−0.007	0.521 ***	0.949 ***	−0.016	−0.006	−0.016	0.609 ***	1.046 ***	−0.020
	(−0.20)	(−0.46)	(4.47)	(4.55)	(−0.86)	(−0.56)	(−0.86)	(4.77)	(4.67)	(−0.96)
hi^2	−0.102 ***	−0.189 ***	−1.366 ***	−3.247 ***	−0.231 ***	−0.085 ***	−0.164 ***	−1.273 ***	−3.051 ***	−0.209 ***
	(−3.66)	(−3.51)	(−3.66)	(−4.04)	(−4.00)	(−2.73)	(−2.90)	(−3.30)	(−3.67)	(−3.68)
L.ued						0.251 ***	0.422 ***	0.807	2.685 **	0.392 ***
						(4.30)	(3.73)	(1.28)	(2.28)	(3.41)
hi * *L.ued*						−0.908 ***	−1.436 ***	−5.429 **	−12.360 **	−1.345 ***
						(−3.13)	(−2.84)	(−1.98)	(−2.43)	(−3.12)
hi^2 * *L.ued*						−3.087 **	−4.745 **	−32.088 ***	−63.258 ***	−5.177 **
						(−2.44)	(−2.07)	(−2.85)	(−3.09)	(−2.22)
year	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Control variables	Control	Control	Control	Control	Control	Control	Control	Control	Control	Control
Constant term	−0.033	−0.132	1.197 **	2.707 **	−0.050	−0.084	−0.205	0.595	1.645	−0.125
	(−0.61)	(−1.37)	(2.04)	(2.34)	(−0.55)	(−1.17)	(−1.58)	(0.92)	(1.23)	(−1.18)
Observed value	145	145	145	145	145	145	145	145	145	145
Adjusted R^2	0.442	0.299	0.336	0.409	0.306	0.480	0.320	0.275	0.353	0.297
F-value	13.90 ***	5.799 ***	3.084 ***	3.311 ***	3.664 ***	14.17 ***	6.750 ***	2.886 ***	2.830 ***	4.781 ***

Note: *, **, and *** represent significance at the 10%, 5%, and 1% levels, respectively. The numbers stated within parentheses are the t-statistics.

Table A2. Robustness test 2.

Variable	Model 1					Model 2				
	roa	***roe***	***tat***	***et***	***sgr***	***roa***	***roe***	***tat***	***et***	***sgr***
L.hi	−0.002	−0.004	0.386 ***	0.609 ***	0.009	−0.012	−0.016	0.437 ***	0.691 ***	0.002
	(0.007)	(0.014)	(0.071)	(0.143)	(0.014)	(0.009)	(0.016)	(0.072)	(0.147)	(0.015)
L.hi^2	−0.088 ***	−0.156 ***	−0.701 ***	−1.270 ***	−0.178 ***	−0.076 ***	−0.167 ***	−0.794 ***	−1.339 ***	−0.171 ***
	(0.025)	(0.049)	(0.227)	(0.453)	(0.052)	(0.028)	(0.054)	(0.226)	(0.474)	(0.054)
L.ued						0.239 ***	0.410 ***	0.799 *	1.634 *	0.331 ***
						(0.053)	(0.103)	(0.466)	(0.954)	(0.096)
L.hi * *L.ued*						−0.577 ***	−0.681 *	−0.964	−3.553	−0.648 *
						(0.224)	(0.399)	(1.826)	(3.676)	(0.343)
L.hi^2 * *L.ued*						−1.485	−2.283	−23.690 ***	−41.870 **	−2.670
						(0.957)	(1.941)	(9.061)	(18.427)	(1.925)
Control variables	Control	Control	Control	Control	Control	Control	Control	Control	Control	Control
Constant term	−0.064	−0.157 *	0.445	0.546	−0.093	−0.089	−0.110	0.490	0.400	−0.075
	(0.045)	(0.083)	(0.404)	(0.846)	(0.078)	(0.056)	(0.103)	(0.456)	(0.974)	(0.096)
Wald chi^2	215.90	78.85	43.64	42.83	54.44	246.27	117.02	66.50	56.21	78.26
Observed value	126	126	126	126	126	126	126	126	126	126

Note: *, **, and *** represent significance at the 10%, 5%, and 1% levels, respectively. The numbers stated within parentheses are the t-statistics.

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Article

Forecasting Guangdong's Marine Science and Technology, Marine Economy, and Employed Persons by Coastal Regions—Based on Rolling Grey MGM(1,m) Model

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Abstract: The development of marine scientific and technological innovation is an important force for realizing the high-quality development of the marine economy. The purpose of this paper is to predict the development trend of marine science and technology development, marine economy, and employed persons by coastal regions in Guangdong Province, and to give policy suggestions for the future direction of the development of marine technology in Guangdong. Considering the new information priority principle, this paper uses the data from 2011 to 2016 to predict the development trend of marine science and technology, marine economy, and employed persons by coastal regions in Guangdong Province from 2017 to 2022 with the rolling RMGM(1,m) model. It is found that the level of marine science and technology and marine economy in Guangdong maintains stable growth, but marine science and technology capabilities still need to be strengthened. On the one hand, the research reveals the development trend of Guangdong's marine science and technology innovation and marine economy, and it provides a direction for the high-quality development of Guangdong's marine economy. On the other hand, the research confirms the validity of the MGM(1,m) model and enriches the research field of grey forecasting models.

Keywords: marine economy; marine science and technology; GM(1,1) mode; RMGM(1,m) model

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1. Introduction

1.1. The Importance of Marine Science and Technology

China's economic development needs the sea [1]. As an important part of modern economic development and social activities, the ocean is the key to achieving economic breakthroughs and innovation [2]. The ocean is a strategic location for high-quality development, and the marine economy has become an important part of the national economy. Innovation is an important driving force for realizing high-quality development of the marine economy [3]. The report of the 19th National Congress of the Communist Party of China stated that innovation is the primary driving force for development and the strategic support for building a modern economic system. Marine technological innovation is an important core of China's high-quality marine development. China attaches great importance to the leading role of marine technological innovation in the development of the marine economy.

China attaches great importance to the innovative development of marine science and technology and has put forward many policies and plans on the construction of marine science and technology. As early as 2008, China promulgated the "Outline of the National Plan for the Development of the Sea by Science and Technology (2008–2015)", and, during the period of 13th Five-Year Plan, the "National Plan for the Development of the Sea by Science and Technology (2016–2020)" and the "13th Five-Year Plan Special Plan for Scientific and Technological Innovation in the Marine Field" were successively issued, which highlight the direction for the work of scientific and technological innovation; these strategies all indicate the importance of marine science and technology. In 2018, the Ministry of Natural Resources issued the “Opinions on Promoting the High-Quality Development of the Marine Economy”, pointing out that technological innovation should play a leading role in the high-quality development of the marine economy. Wang et al. (2021) suggested that the marine economy is a technology-intensive economy, and its development speed and quality are highly related to the development level of marine science and technology. Therefore, in order to develop the marine economy and promote the construction of a marine power, the strategy of promoting the sea through science and technology must be implemented [4].

In this paper, marine R&D activities are selected to measure the development level of marine scientific and technological innovation. Wang et al. (2011) pointed out that science and technology are the primary productive forces, and research and experimental development (R&D) is the most creative and innovative core of scientific and technological activities. Therefore, in the era of knowledge economy, R&D activities are the main driving force for economic and social development [5]. Endogenous growth theory shows that innovation is the internal driving force affecting a country’s economic growth. Romer pointed out that greater innovation factor input in a region leads to a higher economic growth rate [6]. Existing research has proven that innovative elements such as production, patents, and R&D can promote economic growth [7–9]. In recent years, the interaction between R&D investment and economic growth has also become an important field of academic research. Marine R&D can be used as one of the important indicators to measure marine scientific and technological innovation. The development trend of marine R&D investment has become an important basis for the development level of marine science and technology. Therefore, in the present research, we focus on the perspective of marine science and technology innovation and select the marine R&D to measure the level of marine science and technology development.

Marine scientific and technological innovation is also inseparable from scientific and technological innovation talents, who play a crucial role in the development of the country’s marine scientific and technological innovation. Marine science and technology, marine economy, and employed persons by coastal regions are systems that affect each other. In the long run, predicting the future trend of marine science and technology and marine economic growth will play a crucial role in the high-quality development of China ‘s oceans.

1.2. The Development of Marine Science and Technology in Guangdong Province

Guangdong is a major province of marine economy and a pilot area for the development of the national marine economy. According to the “Guangdong Marine Economic Development Report (2021)”, Guangdong’s GOP will exceed 1.7 trillion CNY in 2020, ranking first in the country for 26 consecutive years. In 2020, Guangdong’s GOP accounted for 15.6% of the regional GDP and 21.6% of the national GDP. In 2020, the coastal economic belt created about 82.3% of the province’s total economic output, and it generated 90.7% of the province’s total import and export volume. It can be seen that the development of Guangdong’s marine economy plays an important role in driving Guangdong’s economic development level. To analyze the innovation strategy of marine science and technology, this paper takes Guangdong Province as an example to analyze the innovation level of Guangdong’s marine science and technology. According to China’s Marine Statistical Yearbook, in 2016, there were 3870 scientific and technological personnel in marine scientific research institutions in Guangdong Province, of which about 40% had senior professional titles, and both doctoral and master’s degrees accounted for more than 30%. The number of employed persons by coastal regions has risen steadily, from 3164 in 2012 to 4542 in 2016 with an annual growth rate of 39%.

R&D activities are not only the foundation and core of the entire scientific and technological activities, but also the main driving force for economic and social development. This paper uses marine R&D to measure the development level of marine science and technology in Guangdong. Figure 1 shows the R&D expenditure of Guangdong Province and its proportion in the whole country from 2010 to 2019. As can be seen from Figure 1, R&D in China and Guangdong Province shows a trend of continuous growth. The R&D (100 million CNY) of Guangdong Province increased from 808.7478 in 2010 to 3098.489 in 2019, a nearly fourfold increase. The proportion of R&D in Guangdong Province in the whole country is increasing year by year, which shows that Guangdong Province attaches great importance to the development level of local science and technology.

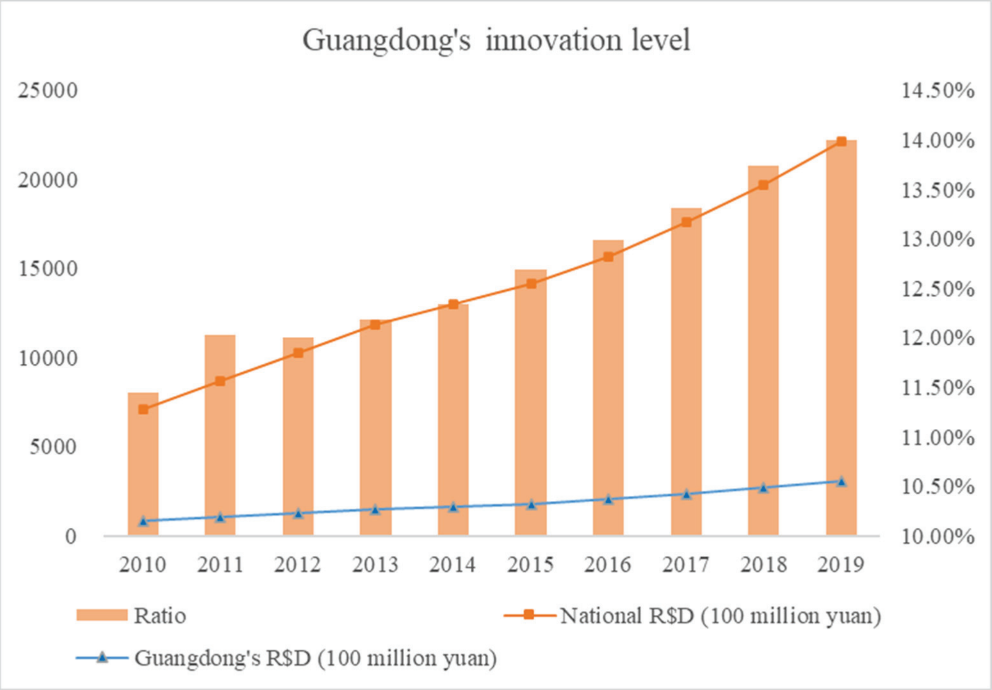

Figure 1. The innovation level science and technology in Guangdong Province. Data source: China Statistical Yearbook of Science and Technology.

Figure 2 shows the marine R&D in Guangdong Province from 2011 to 2016. As shown in Figure 2, the marine R&D (1000 CNY) in Guangdong Province has maintained continuous growth every year from 858,228 in 2011 to 1,966,360 in 2016. The contribution of marine R&D in Guangdong Province to China's R&D has basically maintained an increasing trend, especially in 2016, where the proportion was the largest. In 2016, China's R&D decreased by 21% compared with 2015, but the marine R&D in Guangdong Province in 2016 was able to maintain an increase of 11% compared with 2015. This shows that the level of marine science and technology in Guangdong Province has maintained steady growth year by year.

China's investment in marine R&D is the key to the high-quality development of China's ocean. As a big province of marine science and technology innovation, it is very important to predict the future development trend of marine science and technology and the development of marine economy in Guangdong. The purpose of this paper is to predict the future development of marine science and technology innovation and marine economy in Guangdong Province, and to explore the capacity of marine science and technology innovation in Guangdong Province. This paper can help relevant departments to formulate effective policies and measures for the high-quality development of Guangdong's ocean in the future. The remaining paper is organized as follows: an analysis and a summary of the relevant literature are presented in Section 2. The modeling algorithms of the GM(1,1) model, MGM(1,m) model, and rolling MGM(1,m) model are illustrated in Section 3. The empirical analysis of forecasting Guangdong's marine science and technology, marine economy, and employed persons by coastal regions is provided in Section 4. Conclusions and suggestions are presented in Section 5.

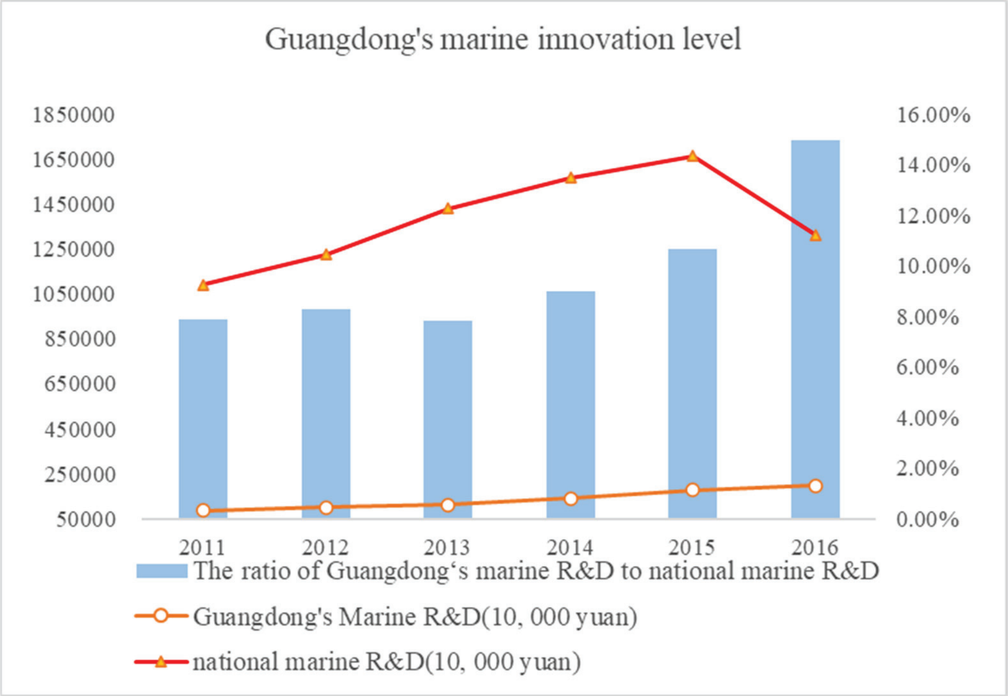

Figure 2. The development level of marine R&D in Guangdong Province. Data source: China Marine Statistical Yearbook.

2. Literature Review

2.1. The Development of Marine Technology Innovation

As China attaches great importance to marine development, many scholars undertook a quantitative analysis of marine economy in China. Wei et al. (2021) used the super-efficiency slack-based measure model and global Malmquist index model to research the impact of the evolution of the marine industrial structure on marine economic [10]. Wu and Li (2022) completed a detailed analysis of the spatiotemporal evolution and types of marine economy and provided a new strategy for measuring many aspects of marine economic resilience [11]. Sun et al. (2021) put forward the AHP-entropy based TOPSIS method to study the sustainable development of the marine economy [12]. Ye et al. (2021) used a differential Gaussian mixture model to study the impact of government preference and environmental regulation on the green development of the marine economy. The results showed that environmental regulation lags behind in promoting the green development of marine economy [13]. Most of the existing research focused on the sustainable study of the marine economy, but seldom discussed predictions of the marine economy. Accurate prediction of the marine economy is helpful to provide a new direction for its rapid development.

In recent years, high-quality marine development has gradually become a hot topic. High-quality marine development is inseparable from marine technological innovation [14]. Many scholars have begun to study marine technological innovation. Relevant research mainly focused on two aspects. First, some scholars constructed marine innovation index systems to analyze the level of marine scientific and technological innovation. For example, Xie (2014) established an evaluation index system for the development level of marine science and technology, and used the principal component analysis method to comprehensively analyze the level of marine science and technology innovation in 11 coastal provinces and cities of China [15]. Sun et al. (2017) constructed an evaluation system of marine economy and marine science and technology in China's coastal areas, and evaluated the level of marine economy and marine science and technology in 11 coastal provinces and cities. The study found that the relationship between marine economy and marine science and technology in various regions is characterized by diversity [16]. Liu and Cui (2016) constructed an evaluation system of marine science and technology competitiveness from three aspects of China's marine economy, including science and technology input, science and technology output, and social and economic development, and they used a spatial econometric model to analyze the influencing factors of marine science and technology competitiveness [17]. The paper provided corresponding policy suggestions for enhancing the competitiveness of marine science and technology.

The second aspect is the efficiency of marine technology innovation or related factors [8]. Shao (2020) used marine patents to represent technological innovation and applied the panel threshold model to examine the nonlinear effects of marine economic growth and technological innovation on marine pollution [18]. Gl et al. (2021) used stochastic frontier analysis (SFA) to calculate the efficiency of marine science and technology innovation [19]. Lw et al. (2021) constructed a panel fixed effect model and random effect model to measure marine science and technology innovation and pointed out ways to strengthen the capacity building of marine science and technology innovation [20]. Pl et al. (2021) used a comprehensive weight model to measure the level of marine technological innovation in China's coastal areas from 2006 to 2016. The results revealed a nonlinear relationship between marine technological innovation and the high-quality development of the marine economy. [21]. Lu et al. (2020) used the stochastic frontier model to measure the input–output efficiency of marine science and technology innovation in 11 coastal provinces and cities in China from 2011 to 2016, and they introduced the time-lag effect to analyze the driving factors of innovation efficiency. The study found that capital investment plays a more important role than personnel investment in marine scientific and technological innovation [22]. The study of the supply chain can provide a new development approach for marine science and technology innovation and further economic benefits of marine related production activities [23,24].

In summary, scholars' research on marine technological innovation mostly adopted traditional statistical analysis methods and models, such as the DEA model, SFA model, spatial econometric model, and panel threshold regression model. Most of the existing research analyzed its influencing factors or the measurement of innovation efficiency, but there have been few studies on forecasting the development of marine science and technology innovation.

2.2. Grey Forecasting Model

Traditional econometric models require larger samples to ensure the accuracy of the model; hence, traditional statistical prediction models have higher requirements on the amount of data, and these data are the key to obtaining the prediction results. However, R&D, an indicator of marine scientific and technological innovation published in China's Marine Statistical Yearbook, has only 6 years of data. China's marine system is greatly affected by uncertain factors, and there is great uncertainty, which greatly limits the availability of models in the traditional sense. Therefore, there are few quantitative studies on the marine field, with a lack of prediction and analysis. In 1982, Chinese scholar Deng founded the grey system theory, which is a new method to study the uncertainty of little data and poor information [25]. Grey prediction is an important part of grey system theory. It discovers and masters the law of system development through the processing of original data and the establishment of grey models, and it makes scientific quantitative predictions about the future state of the system. The grey prediction model is suitable for a system with poor information and for variable prediction with a lack of data, while the calculation of the grey prediction model is simple. Good prediction accuracy can be achieved with fewer data, which makes it widely used. At present, the grey prediction model is being continuously improved. Grey prediction models have been widely used in the integrated circuit industry, environment [26], energy [27], transportation [28], industry [29,30], marine disasters [31], and other fields. Li et al. (2019) comprehensively combined the grey theory and models, explained the validity and extensive application of the grey prediction models, and pointed out that the application of the grey model in the marine economy is an inevitable trend [32].

Considering the scarcity of data on marine science and technology, marine economy, and employed persons by coastal regions, the grey prediction model can be used as a method to predict these three variables.

In grey system theory, the GM(1,1) model and MGM(1,m) model are two important forecasting models in grey forecasting models. In reality, many systems are not just a single variable; thus, the research on grey multivariate models is gradually emerging. Many scholars analyzed the performance of the grey multivariable prediction model and proved its practicability. For example, Zhai et al. (1997) found that, when using the MGM(1,m) model to predict multiple mutually restricting and interacting variables, the prediction accuracy of the MGM(1,m) model is higher than when using the GM(1,1) model for each variable separately [33]. In addition, Xiong et al. constructed a multivariate non-equidistant MGM(1,m) model for the sequence of main non-equidistant features [34], optimized the background value of the MGM(1,m) model [35], and studied the properties of the MGM(1,m) model [36]. The above studies demonstrated the adaptability of the MGM(1,m) model.

Scholars have carried out optimization research on the MGM(1,m) model. Zhang et al. (2020) presented an improved MGM(1,m) model with optimized initial and background values, and the results verified the effectiveness and feasibility of the model [37]. Dai et al. (2018) proposed an extended MGM(1,m) model for monotonic and oscillatory sequences. The empirical results show that the optimized MGM(1,m) model can better solve the problem of the interaction of multiple variables [38]. Wang et al. (2017) comprehensively studied the properties of the MGM(1,m) model, demonstrating the practicability and accuracy of the model [39]. Yuan et al. (2014) applied the background value-improved MGM(1,m) model to the prediction of mechanical failures, and the results showed that the optimized MGM(1,m) model has higher prediction accuracy than the traditional model [40]. Wang and Cao (2021) improved the background value of the MGM(1,m) model and applied it to the prediction of Chinese economic growth, energy consumption, and urbanization. The results showed that the model has a certain prediction accuracy [41].

In summary, the predictive performance of the MGM(1,m) model has been confirmed by some studies showing that the MGM(1,m) model is suitable for predicting variables with poor data. In this paper, the MGM(1,m) model is used to predict the marine science and technology, marine economy, and employed persons by coastal regions in Guangdong. This work can not only achieve otherwise impossible statistical analysis due to the small amount of data in the ocean system, but also enrich the research field of grey prediction models.

3. Methodology

3.1. GM(1,1) Model

Let $X^{(0)}$ be the original sequence of the GM(1,1) model [42],

$$X^{(0)} = (x^{(0)}(1), x^{(0)}(2), \ldots, x^{(0)}(n)).$$

$X^{(1)}$ is the first-order accumulation sequence of $X^{(0)}$,

$$X^{(1)} = \left(x^{(1)}(1), x^{(1)}(2), \ldots, x^{(1)}(n)\right),$$

$$x^{(1)}(k) = \sum_{i=1}^{k} x^{(0)}(i),\ k = 1, 2, \ldots,\ n.$$

$Z^{(1)}$ is

$$Z^{(1)} = \left(z^{(1)}(2), z^{(1)}(3), \ldots, z^{(1)}(n)\right),$$

$$z^{(1)}(k) = \frac{1}{2}\left(x^{(1)}(k) + x^{(1)}(k-1)\right).$$

Thus, the grey differential equation model of GM(1,1) is

$$x^{(0)}(k) + \alpha z^{(1)}(k) = b, \tag{1}$$

where

$$Y_n = \begin{bmatrix} x^{(0)}(2) \\ x^{(0)}(3) \\ \cdots \\ x^{(0)}(n) \end{bmatrix},\ B = \begin{bmatrix} -z^{(1)}(2) & 1 \\ -z^{(1)}(3) & 1 \\ \cdots & \cdots \\ -z^{(1)}(n) & 1 \end{bmatrix},\ \hat{\alpha} = \begin{bmatrix} a \\ b \end{bmatrix}.$$

The error sequence is

$$\varepsilon = Y_n - B\hat{\alpha},$$
$$s = \varepsilon^T \varepsilon = (Y_n - B\hat{\alpha})^T (Y_n - B\hat{\alpha}).$$

According to the least square method, we can get

$$Y = B\hat{\alpha},$$
$$B^T Y = B^T B\hat{\alpha},$$
$$\hat{\alpha} = \left(B^T B\right)^{-1} B^T Y.$$

That is,

$$(\alpha, b)^T = \left(B^T B\right)^{-1} B^T Y.$$

This yields

$$\frac{dx^{(1)}}{dt} + \alpha x^{(1)} = b. \tag{2}$$

Equation (2) is the whitening equation of Equation (1).

(1) The solution of the whitening equation $\frac{dx^{(1)}}{dt} + ax^{(1)} = b$ is also called the time response function,

$$\hat{x}^{(1)}(k+1) = \left(x^{(1)}(0) - \frac{b}{\alpha}\right) e^{-\alpha k} + \frac{b}{\alpha}. \tag{3}$$

(2) The time response sequence of the GM(1,1) grey differential equation $x^{(0)}(k) + az^{(1)}(k) = b$ is

$$\hat{x}^{(1)}(k+1) = \left(x^{(1)}(0) - \frac{b}{\alpha}\right) e^{-\alpha k} + \frac{b}{\alpha},\ k = 1, 2, \ldots, n. \tag{4}$$

(3) The predicted value is

$$\hat{x}^{(0)}(k+1) = \hat{x}^{(1)}(k+1) - \hat{x}^{(1)}(k). \tag{5}$$

3.2. MGM(1,m) Model

The original sequence is $X^{(0)} = \left(X_1^{(0)}, X_2^{(0)}, \ldots, X_m^{(0)},\right)^T$, where $X_j^{(0)}$ represents the sequence of observations of the variable *j* at $1, 2, \ldots, n$, i.e., $X_j^{(0)} = \left\{x_j^{(0)}(1), x_j^{(0)}(2), \cdots, x_j^{(0)}(n)\right\}$, where $j = 1, 2, \cdots, m$.

By accumulating $X_1^{(0)}, X_2^{(0)}, \ldots, X_m^{(0)}$ each time to get $X^{(1)}$, i.e., $X^{(1)} = \left(X_1^{(1)}, X_2^{(1)}, \ldots, X_m^{(1)}\right)^T$, where $X_j^{(1)}$ is the first-order accumulation sequence of $X_j^{(0)}$, we get

$$X_j^{(1)} = \left\{x_j^{(1)}(1), x_j^{(1)}(2), \cdots, x_j^{(1)}(n)\right\},$$

$$x_j^{(1)}(i) = \sum_{k=1}^{i} x_j^{(0)}(k),$$

$$j = 1, 2, \ldots, m, i = 1, 2, \ldots, n.$$

The matrix form of the MGM(1,m) model is

$$\frac{dX^{(1)}(t)}{dt} = AX^{(1)}(t) + B, \tag{6}$$

where

$$X^{(1)}(t) = \left\{x_1^{(1)}(t), x_2^{(1)}(t), \cdots, x_m^{(1)}(t)\right\}^T,$$

$$A = (a_{ij})_{m\times m},\ B = (b_1, b_2, \cdots, b_m)^T.$$

Equation (6) can also be expressed as a first-order differential system.

$$\begin{aligned} \tfrac{dx_1^{(1)}(t)}{dt} &= a_{11}x_1^{(1)}(t) + a_{12}x_2^{(1)}(t) + \cdots + a_{1m}x_m^{(1)}(t) + b_1, \\ \tfrac{dx_2^{(1)}(t)}{dt} &= a_{21}x_1^{(1)}(t) + a_{22}x_2^{(1)}(t) + \cdots + a_{2m}x_m^{(1)}(t) + b_2, \\ &\vdots \\ \tfrac{dx_m^{(1)}(t)}{dt} &= a_{m1}x_1^{(1)}(t) + a_{m2}x_2^{(1)}(t) + \cdots + a_{mm}x_m^{(1)}(t) + b_m. \end{aligned}$$

The time response of the MGM(1,m) model is

$$X^{(1)}(t) = e^{A(t-1)}\left(X^{(1)}(1) + A^{-1}B\right) - A^{-1}B,$$

where

$$X^{(1)}(1) = \left\{x_1^{(1)}(1), x_2^{(1)}(1), \cdots, x_m^{(1)}(1)\right\}^T.$$

By discretizing Equation (6), we can get

$$x_j^{(0)}(k) = \sum_{l=1}^{m} a_{jl}z_l^{(1)}(k) + b_j, \tag{7}$$

where

$$\begin{gathered} z_l^{(1)}(k) = \tfrac{1}{2}(x_l^{(1)}(k-1) + x_l^{(1)}(k), \\ l = 1, 2, \cdots, m,\ k = 2, 3, \cdots, n. \end{gathered}$$

According to the least square method, the parameters can be obtained as

$$\hat{a}_j = (\hat{a}_{j1}, \hat{a}_{j2}, \cdots, \hat{a}_{jm}, \hat{b}_j)^T = (P^TP)^{-1}P^TY_j,$$

where

$$P = \begin{bmatrix} z_1^{(1)}(2) & z_2^{(1)}(2) & \cdots & z_m^{(1)}(2) & 1 \\ z_1^{(1)}(3) & z_2^{(1)}(3) & \cdots & z_m^{(1)}(3) & 1 \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ z_1^{(1)}(n) & z_2^{(1)}(n) & \cdots & z_m^{(1)}(n) & 1 \end{bmatrix},$$

$$Y_j = \left\{x_j^{(0)}(2), x_j^{(0)}(3), \cdots, x_j^{(0)}(n)\right\}^T, j = 1, 2, \cdots, m.$$

We can then get

$$\hat{A} = (\hat{a}_{ij})_{m\times m},\ \hat{B} = (\hat{b}_1, \hat{b}_2, \cdots, \hat{b}_m)^T.$$

If Q, Y_j, and $\hat{a}_j$ satisfy the above conditions,$\hat{a}_j = (\hat{a}_{j1}, \hat{a}_{j2}, \cdots, \hat{a}_{jm}, \hat{b}_j)^T = (P^TP)^{-1}P^TY_j$, the response of the MGM(1,m) model is

$$\hat{X}^{(1)}(k) = e^{\hat{A}(k-1)}(X^{(1)}(1) + \hat{A}^{-1}\hat{B}) - \hat{A}^{-1}\hat{B}. \tag{8}$$

The predicted value is

$$\hat{X}^{(0)}(k)=\hat{X}^{(1)}(k)-\hat{X}^{(1)}(k-1)=\left(e^{\hat{A}(k-1)}-e^{\hat{A}(k-2)}\right)\left(X^{(1)}(1)+\frac{\hat{A}}{\hat{B}}\right)k=2,3,\cdots,n. \tag{9}$$

3.3. The Rolling MGM(1,m) Model

According the priority principle of new information, rolling prediction is added to MGM(1,m), yielding the RMGM(1,m) model [41].

Given raw data $(x_j^{(0)}(1),x_j^{(0)}(2),\cdots,x_j^{(0)}(n))$, we use $(x_j^{(0)}(1),x_j^{(0)}(2),\cdots,x_j^{(0)}(n))$ as the sample data to build the MGM(1,m) model, where n is the sample size for modeling, $(\hat{x}_j^{(0)}(n+1),\hat{x}_j^{(0)}(n+2),\cdots,\hat{x}_j^{(0)}(n+p))$ is the data sequence that needs to be predicted, and p is the total number of data to be predicted.

For $(x_j^{(0)}(1),x_j^{(0)}(2),\cdots,x_j^{(0)}(n))$, we need to predict the value at n + 1, n + 2, ... , n + p, i.e., $(x_j^{(0)}(n+1),x_j^{(0)}(n+2),\cdots,x_j^{(0)}(n+p))$. $x_j^{(0)}(n+1)$ is predicted by sequence $(x_j^{(0)}(1),x_j^{(0)}(2),\cdots,x_j^{(0)}(n))$ according to the MGM(1,m) prediction model. Then, we can predict the value of $x_j^{(0)}(n+2)$, whereby we remove $x_j^{(0)}(1)$ from the original sequence and add the $\hat{x}_j^{(0)}(n+1)$ value of the first prediction. That is, the original sequence of constructing the model becomes $(x_j^{(0)}(2),x_j^{(0)}(3)\cdots,\hat{x}_j^{(0)}(n+1))$, and the predicted value of $\hat{x}_j^{(0)}(n+2)$ can then be obtained using the MGM(1,m) prediction model. This continues until we need to predict the value at time n + p, where the original sequence becomes $(x_j^{(0)}(p),x_j^{(0)}(p+1)\cdots,\hat{x}_j^{(0)}(n+p-1))$. We can use this sequence $(x_j^{(0)}(p),x_j^{(0)}(p+1)\cdots,\hat{x}_j^{(0)}(n+p-1))$ to predict the value of $x_j^{(0)}(n+p)$, and then the value $\hat{x}_j^{(0)}(n+p)$ can be obtained.

The above completes the simulation prediction of $(\hat{x}_j^{(0)}(n+1),\hat{x}_j^{(0)}(n+2),\cdots,\hat{x}_j^{(0)}(n+p))$, and the obtained prediction value is $(\hat{x}_j^{(0)}(n+1),\hat{x}_j^{(0)}(n+2),\cdots,\hat{x}_j^{(0)}(n+p))$.

The above is the modeling process of the RMGM(1,m) model.

3.4. The Measurement of Prediction Error

APE and MAPE are often used to evaluate the performance of predictions. In this paper, APE and MAPE were used to test the prediction accuracy of the MGM(1,m) model.

The absolute residual sequence of the original sequences $x^{(0)}(k)$ and $\hat{x}^{(0)}(k)$ is

$$\Delta_j{}^{(0)}=\left\{\Delta_j{}^{(0)}(k),k=1,2,\ldots,n\right\},\ \Delta_j{}^{(0)}(k)=\left|\hat{x}_j^{(0)}(k)-x_j^{(0)}(k)\right|.$$

The value of APE is

$$\text{APE}=\frac{\Delta_j{}^{(0)}(k)}{x_j^{(0)}(k)}.$$

The value of MAPE is

$$\text{MAPE}=\frac{1}{n}\sum_{k=1}^{n}\frac{\left|\hat{x}_j^{(0)}(k)-x_j^{(0)}(k)\right|}{x_j^{(0)}(k)},$$

where

$$j=1,2,\cdots,m,\ k=2,3,\cdots,n.$$

Smaller MAPE values reflect greater simulation and prediction accuracy [43] (Table 1).

Table 1. MAPE criteria.

MAPE (%)	Forecasting Performance
<10	Excellent
10–20	Good
20–50	Reasonable
>50	Incorrect

4. The Analytics of Prediction

4.1. Collecting Raw Data and Selecting Variables

The aim of this article is the prediction and analysis of the marine science and technology, marine economy, and employed persons by coastal regions in Guangdong. We selected Guangdong's marine R&D, employed persons by coastal regions, and the GOP of Guangdong Province to predict the future development trend of Guangdong's marine technology and marine economy.

Since the government has not released relevant data on marine scientific and technological innovation after 2017, the research period of this paper is from 2011 to 2016. The data sources for this article are the China Science and Technology Statistical Yearbook and China Marine Statistical Yearbook. Table 2 lists the statistics of marine R&D, GOP, and employed persons by coastal regions (EPC) in in Guangdong.

Table 2. Marine R&D, GOP, EPC in Guangdong from 2011 to 2016.

Year	R&D (1000 CNY)	GOP (100 Million CNY)	EPC (10,000 Persons)
2011	858,228	9191.1	820.4
2012	1,015,391	10,506.6	831.6
2013	1,118,513	11,283.6	842.6
2014	1,408,427	13,229.8	852
2015	1,778,965	14,443.1	860.3
2016	1,966,360	15,968.4	868.5

Data source: China Statistical Yearbook of Science and Technology and China Marine Statistical Yearbook.

4.2. Modeling Process and Comparison with Alternative Models

Table 3 summarizes the results of using the MGM(1,m) model and the GM(1,1) model to predict Guangdong's marine R&D, GOP, and employed persons by coastal regions. For the prediction results of the MGM(1,m) model, the prediction error APE was less than 5%, the best prediction result was 0.0067%, and the prediction accuracy was as high as 0.9933%, which shows that the prediction results were excellent. For the prediction results of the GM (1,1) model, most of the prediction errors APE were lower than 5%, but there were individual prediction errors greater than 5%, and the highest prediction error was 5.5421%. Overall, the MGM(1,m) model had a better prediction effect than the GM(1,1) model according to the APE value.

Table 3. Prediction results of MGM(1,m) model and GM(1,1) model.

Year	APE (%) of MGM(1,m)			APE (%) of GM(1,1)		
	R&D	GOP	EPC	R&D	GOP	EPC
2012	1.3617	0.4332	0.0107	2.5562	0.8716	0.1450
2013	1.6185	1.3526	0.0067	5.5421	2.8063	0.0948
2014	0.4455	2.4305	0.0218	0.0028	2.3390	0.1299
2015	3.1838	0.7961	0.0467	5.5377	0.3629	0.0251
2016	4.3072	1.4230	0.0322	1.9630	0.3754	0.1006
MAPE (%)	2.1833	1.2871	0.0236	3.1204	1.3510	0.0991

Figure 3 shows the comparison results of the APE and MAPE of Guangdong's marine R&D between the GM(1,1) model and the MGM(1,m) model. Figure 4 shows the comparison results of the APE and MAPE of the Guangdong's GOP between the GM(1,1) model and the MGM(1,m) model. Figure 5 shows the comparison results of the APE and MAPE of Guangdong's EPC by the GM(1,1) model and the MGM(1,m) model. Using the three graphs, the prediction results of the two models can be clearly compared.

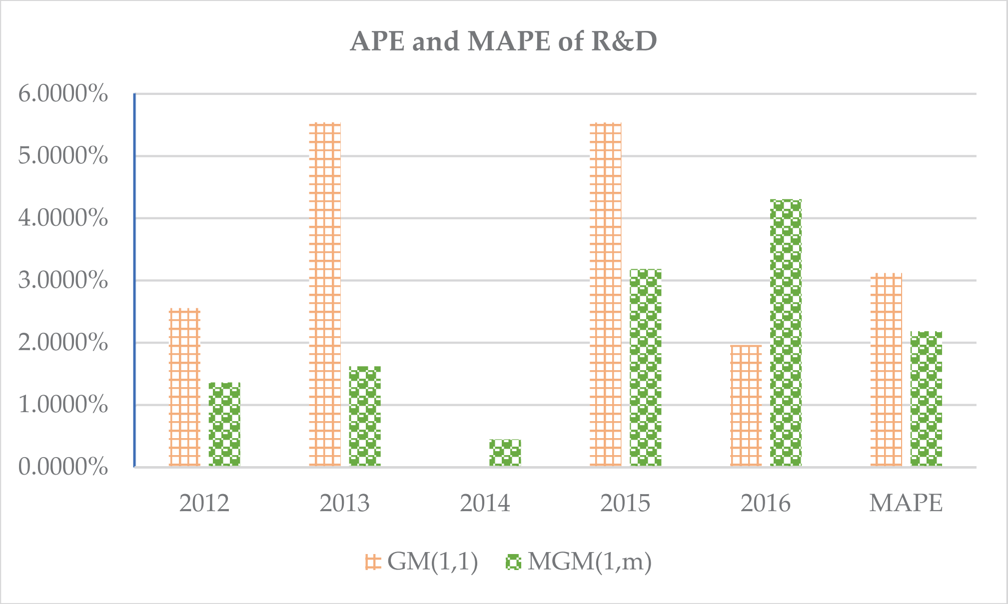

Figure 3. The values of APE and MAPE for Guangdong's marine R&D.

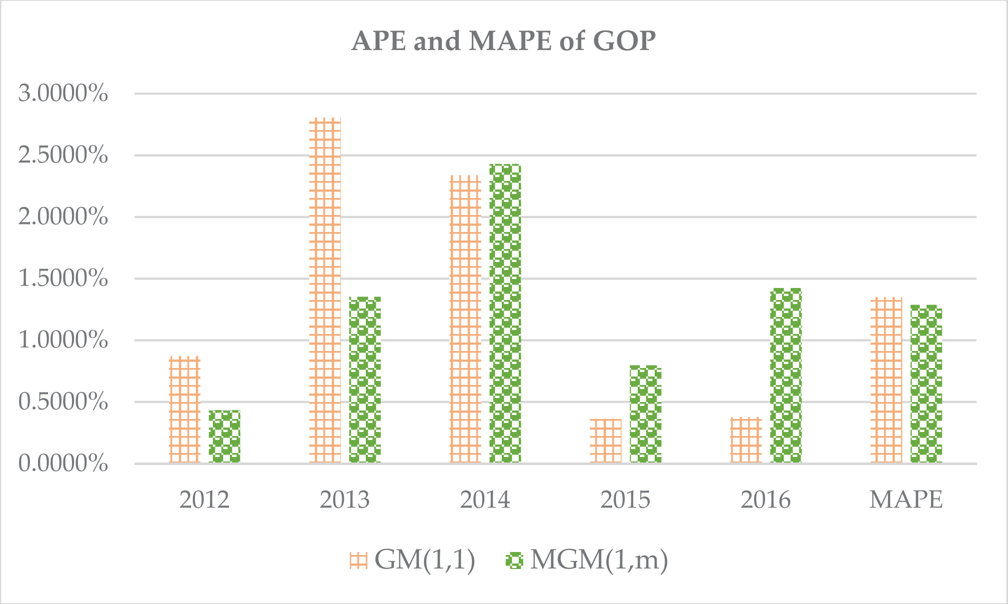

Figure 4. The values of APE and MAPE for Guangdong's GOP.

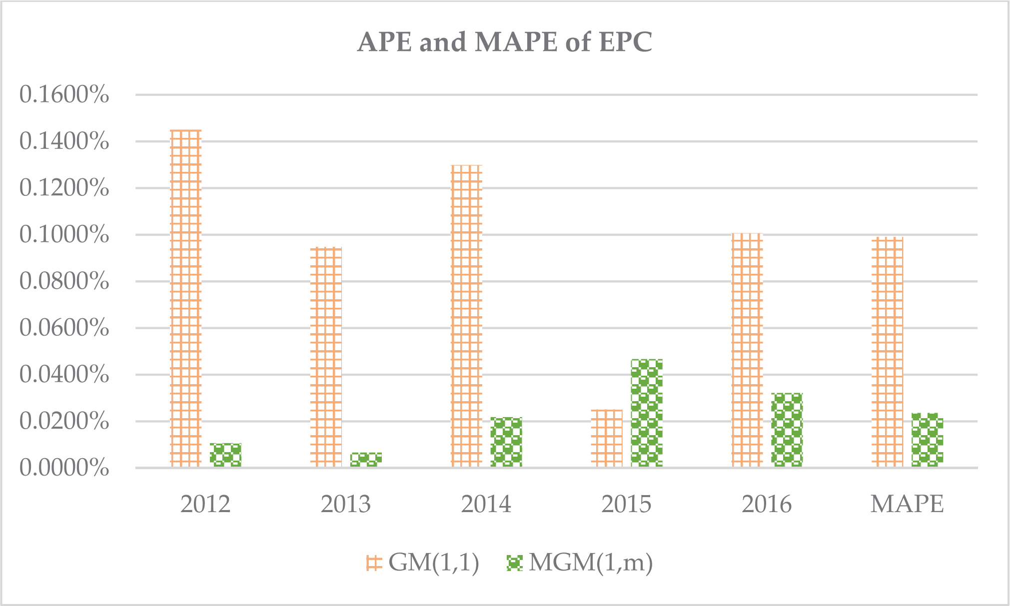

Figure 5. The values of APE and MAPE for Guangdong's EPC.

The MGM(1,m) model and GM(1,1) model of marine R&D had MAPE values of 2.1833% and 3.1204%, respectively. The prediction error was 0.9371% lower than that of the GM(1,1) model. the values of the MGM(1,m) model and GM(1,1) model for GOP were 1.2871% and 1.3510%, respectively. The prediction error of the value was 0.0639% lower than that of the GM(1,1) model. The values of the MGM(1,m) and GM(1,1) models of EPC were 0.0236% and 0.0991%, respectively. The prediction error for EPC values was 0.0755% lower than that of the GM(1,1) model.

These results show that, compared with the GM(1,1) model, the MGM(1,) model had higher fitting and prediction accuracy, and it was more suitable for forecasting marine science and technology, marine economy, and employed persons by coastal regions in Guangdong.

Due to the lack of sample size of Guangdong's marine R&D, the entire forecast sample had only 6 years of data; thus, traditional forecasting models such as regression models or ARIMA models could not be used. Only by using the grey model is it possible to predict and analyze the innovation capability of Guangdong's marine science and technology. From the perspective of data sample size, the validity and applicability of the grey prediction model are further demonstrated.

In summary, according to the APE value and MAPE value of the predicted results, the MGM(1,m) model considering the interaction between variables has higher prediction accuracy than the GM(1,1) model and is more suitable for prediction of marine science and technology innovation systems. Therefore, this paper uses the MGM(1,m) model to predict the marine technological innovation and marine economic development in Guangdong Province. Considering the principle of prioritizing new information, this paper uses the rolling RMGM(1,m) model.

4.3. Future Forecasting

In summary, after comparing the MGM(1,m) model with the GM(1,1) model, we found that the MGM(1,m) model could accurately demonstrate the influence of marine R&D, GOP, and employed persons by coastal regions, and that it had the best and most reliable projecting capability in terms of forecast accuracy. Therefore, we used the RMGM(1,m) model to predict marine R&D, GOP, and employed persons by coastal regions from 2017 to 2022.

From the forecast in Table 4, it can be seen that, from 2017 to 2022, marine R&D, GOP, and employed persons by coastal regions were predicted to maintain an upward trend. A series of policies related to the development of the sea through science and technology issued by China are aimed at further building and improving the national marine science and technology innovation system and improving China's marine science and technology innovation capabilities. Therefore, it is reasonable for Guangdong's marine science and technology level to rise steadily. The level of marine science and technology is closely related to the development of the marine economy, which drives the high-quality development of the marine economy.

Table 4. The future values of R&D, GOP, and EPC predicted by the RMGM(1,m) model.

Variable	2017	2018	2019	2020	2021	2022
R&D (1000 CNY)	2,362,110.381	2,642,164.316	2,886,021.882	3,093,379.101	3,266,674.262	3,409,696.858
GOP (100 million CNY)	17,716.04569	19,069.40491	20,239.88453	21,231.75239	22,060.14674	22,745.17171
EPC (10,000 persons)	874.8862279	880.8407141	886.2144171	891.1222125	895.662112	899.9157609

Figure 6 shows the development trend of Guangdong marine R&D predicted in this paper, and Figure 7 shows the development trend of Guangdong's GOP predicted in this paper. Combining the two development trends, it can be found that the development trends of Guangdong's marine R&D and GOP are basically the same, and the level of marine scientific and technological innovation is closely related to the development of marine economy. Figure 8 shows the development trend of the number of employed persons by coastal regions in Guangdong. From the perspective of the trend, the growth rate of the sea-related employment in Guangdong is relatively slow.

This paper is optimistic about the future level of marine technological innovation and marine economy in Guangdong. The local government should actively adjust the development direction of the marine industry, devote itself to improving the capability of marine technological innovation, and strengthen the implementation of marine technological innovation policies. This can provide strong scientific and technological support for an in-depth understanding of the ocean, rational development of the ocean, and scientific management of the ocean. In addition, strengthening the construction of marine science and technology innovation can significantly improve the sustainable development capacity of the marine industry and coastal economy.

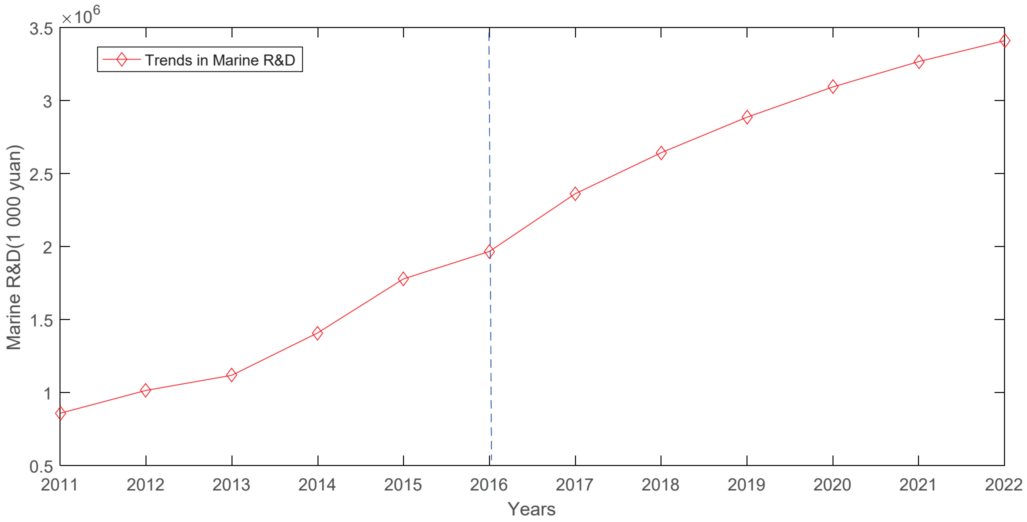

Figure 6. The development trend of Guangdong's marine R&D.

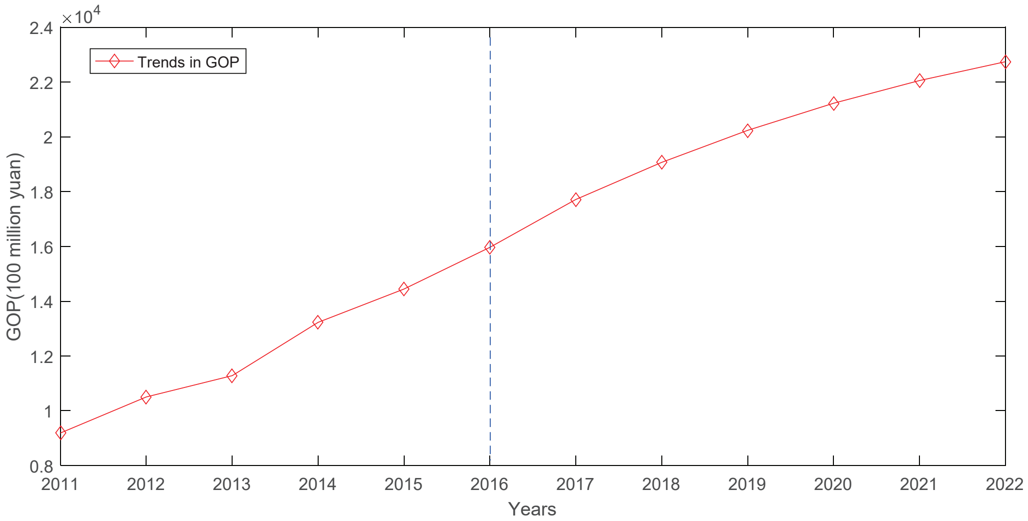

Figure 7. The development trend of Guangdong's GOP.

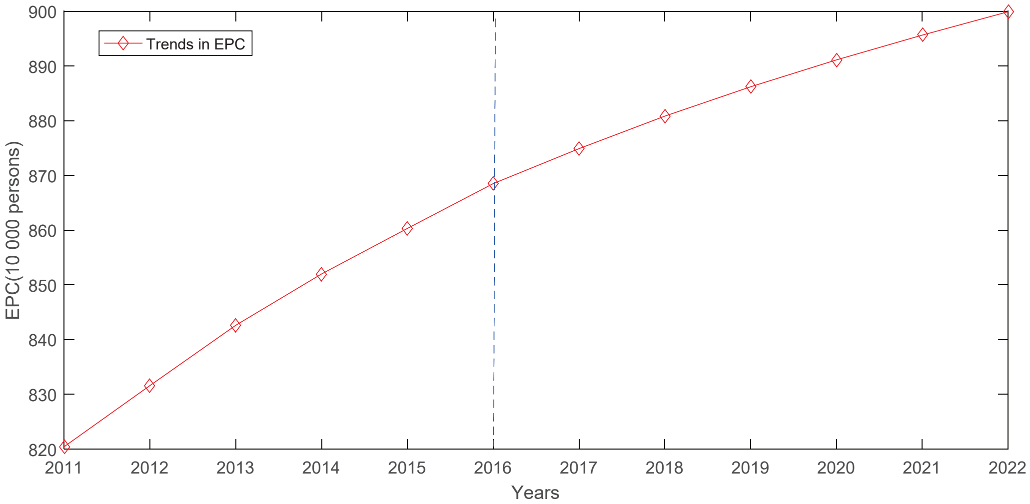

Figure 8. The development trend of employed persons by coastal regions in Guangdong.

5. Conclusions and Suggestions

Under the background of China's comprehensive promotion of marine science and technology innovation capacity building, it is meaningful to study the interactions among marine science and technology innovation capacity, marine economic growth, and employed persons by coastal regions, as well as predict its future development direction and trend. This can promote the close integration of marine technology and marine economy, lead the formation of a new situation for building a powerful marine country, and achieve the goal of high-quality marine development. The improvement of regional marine scientific and technological innovation capabilities and the high-quality development of marine economy are the realistic and major tasks faced by governments at all levels. On this basis, it is very important for us to predict the level of marine science and technology in Guangdong, the development of marine economy, and the employment of marine-related personnel. The research in this paper provides new ideas and methods for future forecasting work in the marine field.

In any predictive analysis, the use of traditional predictive models requires a sufficient sample of data. However, due to insufficient statistical data on marine science and technology in China, traditional prediction models could not be used. Considering the lack of data of marine science and technology, marine economic development, and employed persons by coastal regions in Guangdong and the interactions among the three factors, we used the MGM(1,m) model suitable for small sample analysis and forecasting. According to the experimental results, the MAPE of the RMGM(1,m) for Guangdong's marine R&D was 2.1833%, for Guangdong's GOP was 1.2871%, and for Guangdong's EPC was 0.0236%, which shows that our model performed better than the GM(1,1) model in forecasting performance. Our experimental results proved that the grey multivariate forecasting model has high forecasting accuracy, indicating that the forecasting results are reliable. The results of the model show that, from 2017 to 2022, Guangdong's marine science and technology innovation level, marine economy, and employed persons by coastal regions were predicted to continue growing; thus, the government needs to rationally view the development trend of marine science and technology innovation, as well as the relationship between the marine economy and employed persons by coastal regions. The government should take comprehensive measures and policies to enhance Guangdong's marine science and technology innovation capabilities, stabilize employed persons by coastal regions, and speed up the development of the marine economy. Therefore, this paper proposes two policy recommendations.

(1) Increase investment in marine scientific research funds. The investment of marine scientific research funds is the key to maintaining the steady improvement of marine scientific and technological innovation capabilities. From the current point of view, Guangdong's investment in marine R&D is not strong. In order to further promote the innovative development of the marine industry and accelerate the transformation from a large marine province to a strong marine province, Guangdong needs to continuously increase its investment in marine industry and scientific research, which can fully ensure the smooth progress of marine science and technology innovation activities. In addition, the Guangdong government needs to further support the innovation and development of marine science and technology in terms of scientific research funding and scientific and technological project approval, which can speed up the transformation of scientific research results, and turn input into output as soon as possible.

(2) Increase the training of marine innovative talents. Marine science and technology innovation talents are the foundation of marine science and technology innovation. Guangdong should combine local university platforms to strengthen support for the layout of marine-related majors in colleges and universities, strengthen the construction of marine education and research institutions, and take measures to increase the number of marine-related employment personnel. Talents with certain marine science and technology innovation ability are strong support for the strategy of marine science and technology to revitalize the sea.

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water

Article

Has Technological Progress Contributed to the Bias of Green Output in China's Marine Economy?

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Abstract: At present, the destruction of the marine ecological environment and the imbalance of economic structure have put forward urgent requirements for the green development of the marine economy. Based on the input and output data of China's coastal provinces from 2006 to 2018, the RDM (range directional model) direction distance function was used to measure the output bias technology progress (OBTC) index of each region, and its influence on China's marine economy green total factor productivity (GTFP) was judged accordingly. Furthermore, the rationality of the current OBTC index was studied. The results show that there is obvious output-biased technological progress in China's marine economy, and it has led to the improvement of the GTFP. Although most coastal areas still tend to pursue the improvement of the total output value of the marine economy at the expense of environmental damage, the green bias of China's marine economy has improved significantly since 2015, driven by relevant marine environmental protection policies. From the perspective of different areas, the imbalance of regional development in the process of China's marine economic development is significant. The green bias of the marine economy is highest in the East China Sea area and lowest in the Bohai rim area. However, the coordination between the development of the green marine economy and environmental protection in the South China Sea area needs to be improved.

Keywords: marine economy; green development; the bias of technological progress; the direction distance function; output

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1. Introduction

In the past ten years, the growth rate of China's marine economy has been higher than that of the national economy in the same period, with the gross ocean product (GOP) at the end of the 12th Five-Year Plan reaching 6466.9 billion yuan. China's marine economy is becoming more and more important in the national economy. However, at the same time, a series of problems such as the destruction of marine ecological environment, the imbalance of economic structures, and the expansion of spatial differences have emerged [1]. It shows an extensive development of "high energy consumption and low output" [2]. In this regard, the 2012 report of the 18th National Congress of the Communist Party of China (hereinafter Report) proposed to improve the capacity of marine resources' exploitation and protect the ecological environment. The policy reflects the urgent need for green development of the marine economy, which means that related industries are required to adjust production in the direction of reducing environmental damage [3]. However, the gap between the regions in green development is large, and coordination is insufficient, which is not conducive to the steady development of the marine economy [4,5]. The key to improving the equilibrium of green marine economic development between regions lies in making clear the regions' objective conditions and comparative advantages, and accordingly, formulating local development strategies, rationally allocating various factors of production, and highlighting their own development priorities to promote the coordinated development of the regions.

The development of marine economy is inseparable from various inputs [6], and the impact of inputs on outputs is two-sided. When the desirable output is obtained, it inevitably results, in part, in an undesirable output, namely marine pollution [7]. It has led to the loss of living marine resources and the deterioration of marine sites [8,9]. With the depletion of marine resources and the increasing input of marine industry, the sustainable growth of the marine economy is facing serious challenges, which put forward higher demands on the efficiency of green output [10,11]. Improving the efficiency of green output is to enhance the role of technological progress on desirable output and reduce the proportion of undesirable output, which reflects the degree of green bias of marine economic development. It can be seen that the bias of technological progress from the output perspective is the main reason for the uneven degree of green bias, which has a very important impact on the sustainable development of the marine economy.

At present, the research on the biased technological progress of China's marine economy mainly has focused on the impact of capital, labor, and resources on marine economic growth, that is, from the perspective of input, to analyze the sources of China's uneven marine economic development [12–14]. However, there is little research that explores whether the current process of China's marine economic development is in harmony with the protection of the ecological environment from the perspective of output. Exploring the green growth of marine economy from the output perspective can more intuitively reflect the difference in the degree of green bias. Measuring the degree of green bias of the output in different areas is conducive to the implementation of environmental protection measures adapted to local conditions, which can improve the effective output efficiency, promote interregional coordinated development, and promote the high-quality development of China's marine economy.

Since the 21st century, the connotation of sustainable development has been continuously enriched [15–19], however, with the further depletion of land resources, the development of the marine economy has become a new hot spot in global economic development [20–22]. Giving full play to the leading role of technological progress in the bias of green output, reducing marine environmental pollution and enhancing the total output value of the ocean are important requirements for the marine technological progress of the present sustainable development goals. Exploring the degree of coordination between technological progress and the bias of green output in the marine economy is the starting point of this paper. This work makes the following main contributions to the existing literature by:

i. using the directional distance function based on RDM, the Chinese marine GTFP was measured and decomposed to obtain the OBTC index of each coastal province from 2006 to 2018, to judge whether there is obvious output-biased technological progress in the development process of China's marine economy.
ii. analyzing the rationality of the current output-biased technological progress, and judging whether the technological progress of each province in each year has promoted the green output bias of China's marine economy from the two dimensions of time and space, and then identifying the non-efficient areas and providing guidance for them to improve the input–output structure and optimize resource allocation.

2. Materials and Methods

2.1. Study Area

The total area of China's four major seas is more than 4.7 million square kilometers, spanning 32 longitudes of east to west and 44 latitudes from north to south. The mainland coastline, from the Yalu River estuary in Liaoning province to Beilun Estuary in Guangxi, has a total length of 18,000 km, ranking fourth in the world. In China, there are more than 6960 islands, large and small, with a total island area of nearly 80,000 square kilometers and a total island coastline of about 14,000 km. Rich marine resources and good location advantages are the superior basic conditions for the rapid development of the marine economy [23].

2.2. Methods

2.2.1. Nonparametric Methods Based on the DEA (Data Envelopment Analysis)

At present, the measurement method of biased technological progress is mainly divided into the parameter method and non-parameter method. The former is mostly based on pre-determined forms of production functions, estimating the alternative elasticity between factors, and using them as a basis for analyzing the bias of technological progress [24,25]. The latter is represented by the DEA method [26,27], which does not require the designation of a special form of production function, avoiding the estimated deviation due to pre-determined production functions. In addition, the parameter method also needs input and output variable price data, but the pollutant price data collection is difficult, and pricing by external influence is not necessarily reasonable. Therefore, the strict measurement conditions of the parametric method make it difficult to achieve. However, the nonparametric method only needs to set input and output variables, and the measurement conditions are easy to satisfy [28]. In addition, unlike the parameter method, the DEA model can solve the problem of multi-input and multi-output and has been used in many fields [29–32]. In a word, the non-parametric method based on DEA was more operable and suitable for this study.

Specifically, this paper used the DEA method to measure the green Malmquist-Luenberger (ML) index and then used this index to represent the change in GTFP. Then, referring to Fare's approach [33], the GTFP index was broken down into two parts, the technology change (TC) index and the technology efficiency change (EC) index, wherein the former can be broken down into the input-biased technological progress (IBTC) index, OBTC index, and technology scale change (MATC) index. Finally, based on the research of Weber and Dominzlicky [34], the paper compared the OBTC index with the cross-period change of output combination, to judge the output bias of marine technology; that is, whether marine technology is biased towards reducing pollution emissions and provides a basis for further discussion of the relationship between marine resources, environment, and development in China.

2.2.2. The Direction Distance Function Based on the RDM

Traditional DEA models cannot process data sets that contain undesirable outputs, i.e., pollution of the marine environment, as undesirable output makes it more difficult to measure productivity growth. Therefore, to solve this problem, this paper refers to the method of Portela et al. [35] and improved the direction distance function based on RDM. This function can evaluate a data set containing undesirable outputs (e.g., marine wastewater, marine exhaust gas, marine solid waste) with the advantages of unit invariance, translational invariance, and the improvement of the invalid unit, with it being closer to the effective frontier. In particular, the direction vector of RDM is the possible improvement of the decision-making unit, which does not change the original undesirable output data, and improves the authenticity and reliability of the efficiency estimation results [36].

In this paper, the marine production of each coastal province was regarded as the decision-making unit, and the following definition was made: the decision-making unit set is $J = \{1, \cdots, n\}$, the input vector of the m marine production factors of the estimated unit K is $x_{ij} = \left(x_{1j}^t, \cdots, x_{mj}^t\right) \in R^+$, the output vector includes p desirable outputs and q undesirable outputs $y_{b_v} = \left(y_{b_1 j}^t, \cdots, y_{b_q j}^t\right) \in R^+$, $p + q = s$. $g^t = \left(g_x^t, g_y^t\right)$ is a set of vectors that reflect the direction of change in input and output. RDM sets the combination of minimum input and maximum output for the t-period as the ideal point IP, which satisfies $IP_i^t = \underset{J}{min}\left\{x_{ij}^t\right\}$, $i = 1, \cdots, m$ for input x_i, $IP_{g_u} = \underset{J}{max}\left\{y_{g_u j}^t\right\}$, $u = 1, \cdots, p$ for output y_{g_u}, $IP_{b_v} = \underset{J}{min}\left\{y_{b_v j}^t\right\}$, $v = 1, \cdots, q$ for output y_{b_v}. The direction vector based on the RDM can then be expressed as:

$$\left(g_x^t, g_y^t\right) = \left(R_x^t, R_{y_g}^t, -R_{y_b}^t\right) = \left(R_{x_1}^t, \cdots, R_{x_m}^t, R_{y_{g_1}}^t, \cdots, R_{y_{g_p}}^t, -R_{y_{b_1}}^t, \cdots, -R_{y_{b_q}}^t\right)$$

where $R_x^t = x_i^t - \underset{j}{min}\left\{x_{ij}^t\right\}, \hat{R}_{y_g}^t = \underset{j}{max}\left\{y_{guj}^t\right\} - y_{gu}^t, R_{yb}^t = y_{b_v}^t - \underset{J}{min}\left\{y_{b_vj}^t\right\}$. Thus, the RDM directional distance function can be obtained as:

$$\vec{D}^t\left(x^t, y_g^t, y_b^t; R_x^t, R_{y_g^t}, -R_{y_b^t}\right) = sup\left\{\beta : x^t - \beta R_{x^t}, y_g^t + \beta R_{y_g^t}, y_b^t - \beta R_{y_b^t}\right\} \tag{1}$$

2.2.3. Measurement of the OBTC Index

When the input is given, the output distance function describes the characteristics of the production technique by comparing the changes brought about by the expansion of the maximum proportion of each output combination. Assuming that the output that reflects technological changes may be set to $p^t(x) = \left\{(y_g, y_b) : x \text{ can produce } (y_g, y_b)\right\}$, the RDM output distance function can be expressed as: $\vec{D}_o^t\left(x^t, y_g^t, y_b^t; R_{y_g^t}, -R_{y_b^t}\right)$ $= sup\left\{\beta : y_g^t + \beta R_{y_g^t} \in p^t(x), y_b^t - \beta R_{y_b^t} \in p^t(x)\right\}$.

Then, the output technical efficiency value of the decision-making unit DMU_k can be obtained by solving the following linear planning problems that meet the constraints of constant scale compensation:

$$\begin{gathered}\vec{D}_o^t\left(x^t, y_g^t, y_b^t; R_{y_g^t}\right) = max\left\{\beta_k \mid \Sigma_{j=1}^n z_j^t x_{ij}^t \le x_{ik}^t,\ i = 1, \cdots, m\right. \\ \Sigma_{j=1}^n z_j^t y_{gwj}^t \ge y_{guk}^t + \beta_k R_{y_{guk}^t},\ u = 1, \cdots, p \\ \Sigma_{j=1}^n z_j^t y_{b_vj}^t \le y_{b_vk}^t - \beta_k R_{y_{bv}^t},\ v = 1, \cdots, q \\ \Sigma_{j=1}^n z_j^t = 1,\ z_j^t \ge 0\end{gathered} \tag{2}$$

Then, using the methods of Chung et al. [37], based on the Malmquist index model, the distance function containing undesirable output is considered to construct the ML index. At a certain input, $D_o^t\left(y_g^t, y_b^t, x^t; R_{y_g^t}, -R_{y_b^t}\right)$ and $D_o^{t+1}\left(y_g^{t+1}, y_b^{t+1}, x^{t+1}; R_{y_g^t}, -R_{y_b^t}\right)$ represent the direction distance functions of period t and period $t+1$, respectively, when $R_x = 0$. The ML index decomposition method is used to measure a series of indicators. The model is as follows:

$$ML = \sqrt{\frac{D_i^{t+1}\left(y_g^{t+1}, y_b^{t+1}, x^{t+1}; R_{y_g^t}, -R_{y_b^t}\right)}{D_i^{t+1}\left(y_g^t, y_b^t, x^t; R_{y_g^t}, -R_{y_b^t}\right)} \times \frac{D_i^t\left(y_g^{t+1}, y_b^{t+1}, x^{t+1}; R_{y_g^t}, -R_{y_b^t}\right)}{D_i^t\left(y_g^t, y_b^t, x^t; R_{y_g^t}, -R_{y_b^t}\right)}} \tag{3}$$

Decomposition then obtains:

$$ML = EC \times TC = \frac{D_i^{t+1}\left(y_g^{t+1}, y_b^{t+1} x^{t+1}; R_{y_g^t}, -R_{y_b^t}\right)}{D_i^t\left(y_g^t, y_b^t, x^t; R_{y_g^t}, -R_{y_b^t}\right)} \times \sqrt{\frac{D_i^t\left(y_g^t, y_b^t, x^t; R_{y_g^t}, -R_{y_b^t}\right)}{D_i^{t+1}\left(y_g^t, y_b^t, x^t; R_{y_g^t}, -R_{y_b^t}\right)} \times \frac{D_i^t\left(y_g^{t+1}, y_b^{t+1}, x^{t+1}; R_{y_g^t}, -R_{y_b^t}\right)}{D_i^{t+1}\left(y_g^{t+1}, y_b^{t+1}, x^{t+1}; R_{y_g^t}, -R_{y_b^t}\right)}} \tag{4}$$

Using the method of Fare et al. [34], the TC index is further decomposed to obtain the neutral technology progress index and the biased technology progress index:

$$MATC = \frac{D_i^t\left(y_g^t, y_b^t, x^t; R_{y_g^t}, -R_{y_b^t}\right)}{D_i^{t+1}\left(y_g^t, y_b^t, x^t; R_{y_g^t}, -R_{y_b^t}\right)} \tag{5}$$

$$IBTC = \sqrt{\frac{D_i^{t+1}\left(y_g^t, y_b^t, x^t; R_{y_g^t}, -R_{y_b^t}\right)}{D_i^t\left(y_g^t, y_b^t, x^t; R_{y_g^t}, -R_{y_b^t}\right)} \times \frac{D_i^t\left(y_g^t y_b^t, x^{t+1}; R_{y_g^t}, -R_{y_b^t}\right)}{D_i^{t+1}\left(y_g^t, y_b^t, x^{t+1}; R_{y_g^t}, -R_{y_b^t}\right)}} \tag{6}$$

$$OBTC = \sqrt{\frac{D_i^t\left(y_g^{t+1}, y_b^{t+1}, x^{t+1}; R_{y_g^{t+1}}, -R_{y_b^{t+1}}\right)}{D_i^{t+1}\left(y_g^{t+1}, y_b^{t+1}, x^{t+1}; R_{y_g^{t+1}}, -R_{y_b^{t+1}}\right)} \times \frac{D_i^{t+1}\left(y_g^t y_b^t, x^{t+1}; R_{y_g^t}, -R_{y_b^t}\right)}{D_i^t\left(y_g^t, y_b^t, x^{t+1}; R_{y_g^t}, -R_{y_b^t}\right)}} \tag{7}$$

And TC = MATC × IBTC ×OBTC.

With constant returns to scale, Shephard's input distance function is equal to the reciprocal of output distance function [35], i.e.,

$$D_i^t\left(y_g^t, y_b^t, x^t\right) = D_0^t\left(x^t, y_g^t, y_b^t\right)^{-1} \tag{8}$$

An output oriented OBTC index is computed as follows:

$$OBTC = \sqrt{\frac{D_0^t\left(x^{t+1}, y_g^{t+1}, y_b^{t+1}; R_{y_g^{t+1}}, -R_{y_b^{t+1}}\right)}{D_o^{t+1}\left(x^{t+1}, y_g^{t+1}, y_b^{t+1}; R_{y_g^{t+1}}, -R_{y_b^{t+1}}\right)} \times \frac{D_o^{t+1}\left(x^{t+1}, y_g^t, y_b^t; R_{y_g^t}, -R_{y_b^t}\right)}{D_0^t\left(x^{t+1}, y_g^t, y_b^t; R_{y_g^t}, -R_{y_b^t}\right)}} \tag{9}$$

Among them, OBTC in the Formula (9) reflects the bias promotion effect of technological progress on different outputs, that is, the calculation formula of the OBTC index in this paper. When there is only one output, the value of the index is always 1 [38].

In the above formula, the ML, EC, TC, MATC, IBTC, and OBTC indices all represent the rate of change between period t and $t + 1$. The change rate index is greater than (less than) 1, indicating that the indicator is larger (decrease) than the previous period.

2.2.4. The Method of Judging Output Bias

Figure 1 shows the principle of identification of the output bias of technological progress. In this paper, two output indicators (desirable output is the value added of the marine industry and undesirable output is marine pollutant emission index) were constructed in the model, represented by the letters y_g, and y_b respectively. In Figure 1, $P^1(x)$ represents the production probability curve for period t_1, and $P^2(x)$ represents the outflow of the output probability curve for period t_2, which is Hicks-neutral, given that the marginal rate of transformation (MRT) of two outputs remains constant. Direction vectors g^{t1} and g^{t2} indicate the direction in which output-biased technological progress has contributed to the improvement of economic production (increase desirable output y_g, reduce undesired output y_b) in two periods, respectively.

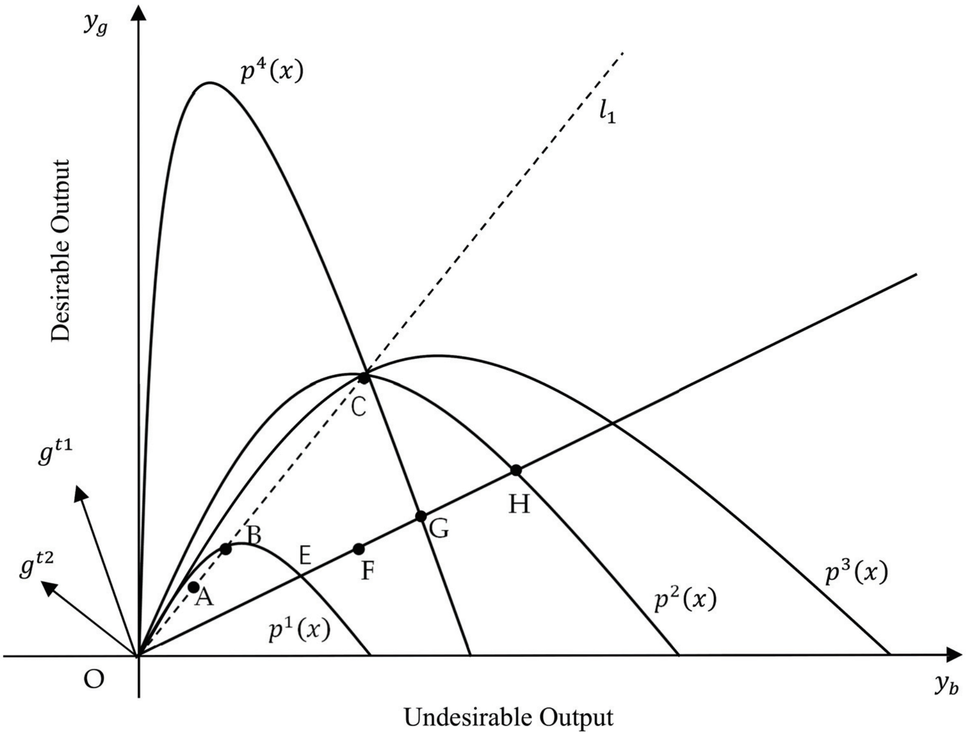

Figure 1. Changes in the possible set of production under the two-output model.

If the MRT of y_g to y_b increases from period t_1 to period t_2, then the technological progress in output will be biased towards production y_g, which, in the Figure, can be shown as $P^1(x)$ moving to $P^4(x)$. Similarly, from period t_1 to period t_2, the MRT of y_g to y_b decreases, then, the technological progress of the output will be biased towards production y_b, shown in the Figure as $P^1(x)$ moving to $P^3(x)$.

The following is an example of how to judge the bias of a particular output. If point *A* represents an inefficient combination of outputs in period t_1, and points *B* and *C* intersect with $P^1(x)$ and $P^4(x)$ by rays passing through points *O* and *A*, respectively, the output direction distance function value is $\overrightarrow{D_o^1}(x^{t1}, y_g^{t1}; g^{t1}) = \frac{OB}{OA}$. In period t_2, it is assumed that the output combination point is *F* and that the set of production possibilities becomes $P^4(x)$, and points *E* and *G* intersect with $P^1(x)$ and $P^4(x)$ by rays passing through points *O* and *F*, respectively. Point *F* is below the l_1 curve, so the MRT_{gb} (The ratio of desirable and undesirable outputs across periods) is less than 1, i.e., $\frac{y_g^{t+1}}{y_b^{t+1}} < \frac{y_g^t}{y_b^t}$. According to Formula (9), the output distance function value is $\overrightarrow{D_o^2}\left(x^{t2}, y_g^{t2}; g^{t2}\right) = \frac{OG}{OF}$. The values are substituted for equations and OBTC=$\sqrt{\frac{OE/OF}{OG/OF} \times \frac{OC/OA}{OB/OA}} = \sqrt{\frac{OE/OG}{OB/OC}} > 1$. When combined with the $P^4(x)$ curve moving in the direction of fit y_g, it can be concluded that when OBTC > 1 and $MRT_{gb} < 1$ ($MRT_{bg} > 1$), with output-biased technological progress towards producing y_g. When combined with this law, this paper obtained the bias direction of technological progress to different outputs by calculating the MRT and the OBTC value, which was calculated by software.

When combining the cross-period changes of marine inputs and outputs with the corresponding OBTC index, the specific bias determination rules of output-biased technological progress in Table 1 were obtained, i.e., the basis for determining whether technological progress is biased towards environmental protection (y_g for value added of GOP, y_b for marine economic pollutant emissions):

Table 1. The method of judging output bias.

Output Mix	OBTC > 1	OBTC = 1	OBTC < 1
$\frac{y_g^{t+1}}{y_b^{t+1}} < \frac{y_g^t}{y_b^t}$	y_g	neutrality	y_b
$\frac{y_g^{t+1}}{y_b^{t+1}} > \frac{y_g^t}{y_b^t}$	y_b	neutrality	y_g

2.3. Data Acquisition

The paper analyzed the panel data of 11 provinces along China's coast from 2006 to 2018 (Figure 2). The data are mainly from the 2007–2019 China Marine Statistics Yearbook, the China Statistical Yearbook, and the China Environmental Statistics Yearbook. The missing data are supplemented by the interpolation method. Considering the resource and environmental constraints in the marine economic system, this paper incorporated the utilization of marine resources and their impact on the environment into the evaluation system based on capital and labor inputs.

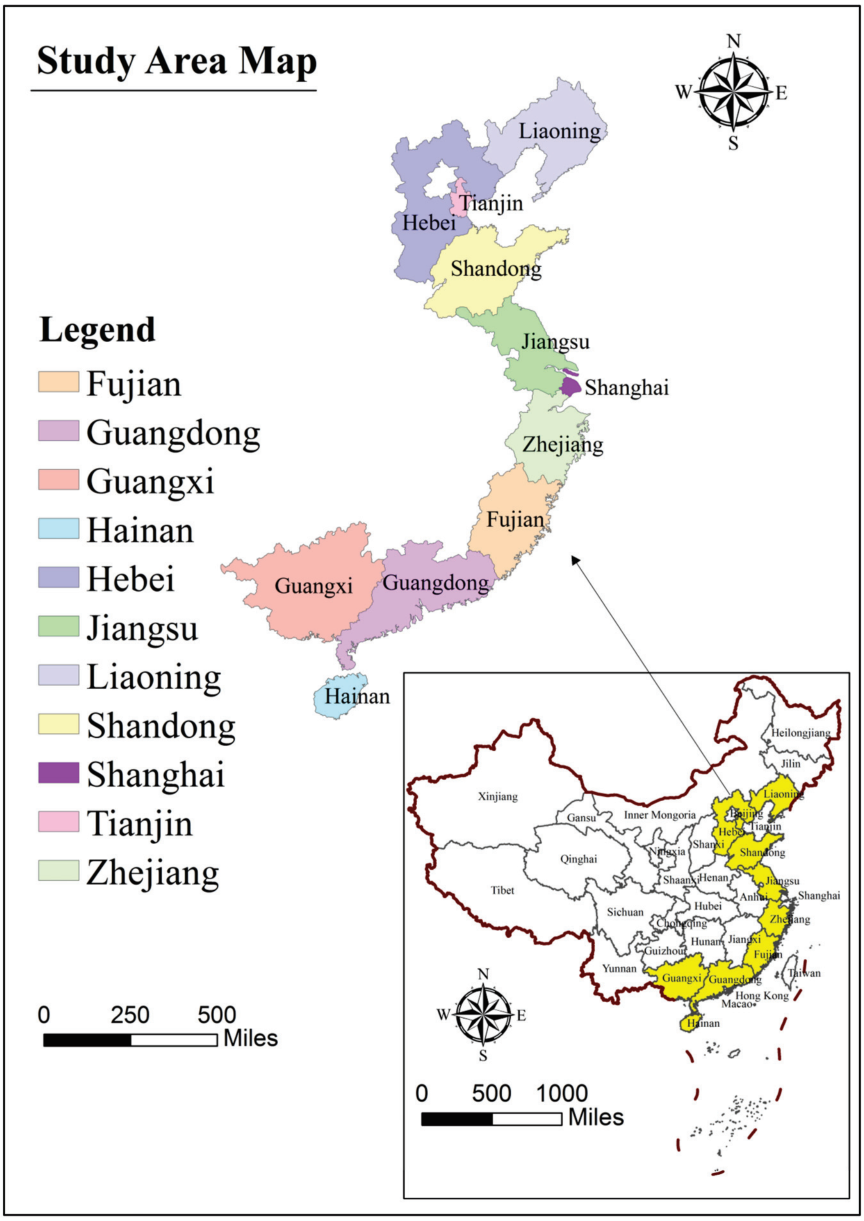

Figure 2. Map of China's coastal areas.

The specific indicators are as follows:

2.3.1. Input Indicator

(1) Capital.

In this paper, the marine economic capital stock was used as the capital input index. The capital stock measures the total cost of construction and acquisition of fixed assets related to production activities over a period. Referring to the research of Shan [39], this paper used the perpetual inventory method to measure the fixed assets of 11 coastal areas. As shown in Formula (10):

$$K_{i,t} = I_{i,t}/P_{i,t} + (1 - \delta_{i,t})K_{i,t-1} \tag{10}$$

$K_{i,t}$ and $K_{i,t-1}$ represent the capital stock in period t and t_1 respectively, $I_{i,t}$ indicates the investment for the current year, expressed in terms of fixed asset completions, and $P_{i,t}$ represents the fixed asset investment price index for each province for the year. This paper selected 2006 as the base period and drew on Xu's treatment method [40] to determine the capital stock of the base period in each region as: $K_{i,2006} = I_{i,2006}/(\delta_{2006} + g_{iy})$, and g_{iy} to the average annual growth rate of the i region for 2006–2018. $\delta_{i,t}$ represents the depreciation rate of the total amount of fixed asset formation. Drawing on the practice of Shan [39], $\delta_{i,t}$ takes the value of 10.96%. Finally, the capital stock data of coastal provinces were converted into marine economic capital stock by reference to the research of He et al. [41]. The formula is as follows:

$$K_{it_m} = K_{it} \times \frac{Y_{it_m}}{Y_{it}} \tag{11}$$

Among them, Y_{it}, K_{it}, Y_{it_m}, and K_{it_m} represent the gross domestic product (GDP), capital stock, GOP, and marine capital stock of coastal provinces, respectively.

(2) Labor.

In the Marine Economic Statistics Yearbook, after 2006, the number of sea-related employees in coastal areas was used to reflect the amount of labor input, which has been used until now, and the data is comparable. Therefore, with reference to the results of national economic research, the paper selected this indicator to measure labor input and records it as L.

(3) Resource.

Because the development of the marine economy is highly dependent on resource endowment, the input of marine resources is very important to the development of marine economy. Drawing on the practice of Zhao et al. [42], this paper selected the length of the wharf, the number of coastal travel agencies, and the area of marine aquaculture. It was then converted using the entropy method as a comprehensive indicator of resource input. The calculation process for the composite indicators is as follows:

i. Non-quantitative processing of indicators. The original indicator data matrix is $X_{ij} = \left(x_{ij}\right)_{m\times n}$, wherein the X_{ij} is the value of the regional i indicator j, the proportion of this value is $X_{ij} = X_{ij}/\sum_{i=1}^{m} X_{ij}$. Therefore, the original matrix can be converted into a scaleless matrix $X'_{ij} = (x'_{ij})_{m\times n}$.
ii. Calculate the entropy value e_j of indicator j: $e_j = -\frac{1}{ln\ m}\sum_{i=1}^{m} X'_{ij} ln x_{ij},\ e_j \geq 0$.
iii. Calculate the difference coefficient e'_j of indicator j. Given the indicator j, the smaller the difference between the X'_{ij} of each sample, the greater the entropy value e'_j, the smaller the role of indicator j in the comprehensive evaluation. We define $e'_j = 1 - e_j$, So, the bigger the e'_j, the more important the indicator j is in the comprehensive evaluation.
iv. Calculate the objective weight of indicator j: $w_j = e'_j/\sum_{j=1}^{n} e_j = \left(1 - e_j\right)/\sum_{j=1}^{n}\left(1 - e_j\right)$.
v. Calculate the composite index of resource inputs h: $h = \sum_{j=1}^{n} X'_{ij} w_j$.

Through the above measurement steps, the weights of the length of the wharf, the number of coastal travel agencies and the area of marine aquaculture in 2006–2018 were 0.219, 0.167, and 0.614 respectively, and the resource input index was obtained as the final value according to the comprehensive weighting of this weight.

2.3.2. Output Indicator

(1) Desirable output.

The economic benefits brought by marine resources can well reflect the development of the marine economy [43,44]. Therefore, the GOP was used as the desirable output of the model. The regional GOP was converted to constant price levels on a 2006 basis [45].

(2) Undesirable output.

Marine economy is similar to the national economy, in that the production and operation process will also have a negative impact on the ecological environment. Therefore, based on taking full account of the particularity and data accessibility of the marine economy, we followed the practice of Zang [46] and used the research results of Zeng [47] to select marine wastewater, marine exhaust gas, and marine solid waste emissions as environmental pollution indicators.

Marine industrial pollution emissions were converted according to "(GOP/GDP) × industry pollution emissions". Then, using the entropy method, the weights of total marine wastewater discharge, total exhaust emission, and solid waste emission were 0.150, 0.127, and 0.723 respectively, according to which the three indicators of marine "three waste" emissions were combined into a comprehensive index of marine environmental pollution H [48]. This was used as an indicator of undesirable outputs. The larger the indicator, the more serious the pollution of the marine environment. China's coastal environmental pollution index is shown in Figure 3:

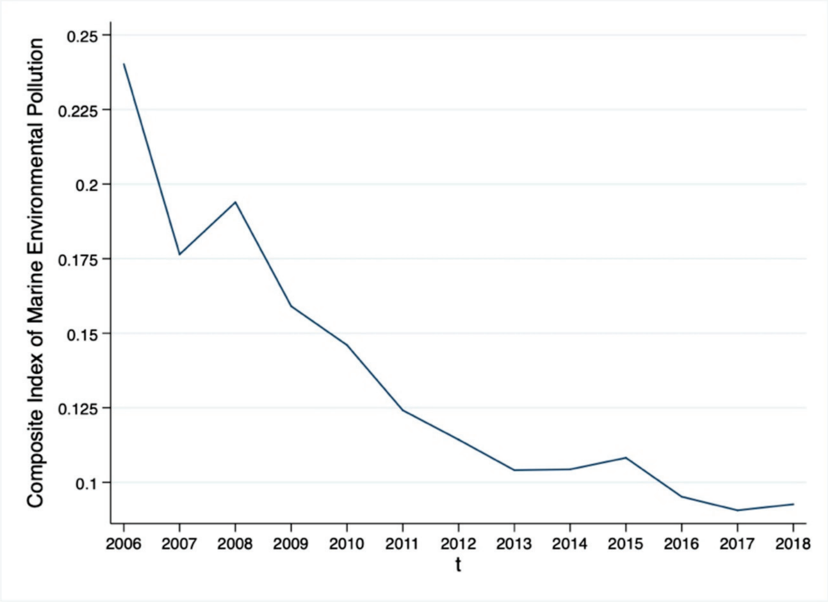

Figure 3. Composite index of marine environmental pollution.

As can be seen from Figure 3, the pollution index H in 2006–2018 shows a small range of fluctuations and an overall downward trend. Specifically, before 2008, the fluctuation of marine environmental pollution index in coastal areas of China was relatively obvious. At this stage, the marine economy has been constantly subjected to structural adjustment, the development of which is relatively extensive. Between 2008 and 2013, the comprehensive index H began to decline year by year. This is mainly due to the formulation and implementation of the government's policies on the regulation of the marine environment, as well as the continuous promotion of marine environmental protection. After 2013, the pollution index H showed a steady downward trend, which was due to the implementation of policies, a positive effect of the previous policy on the environment that was highlighted. The development of marine green production technology has made the marine environmental protection stable and progressive during this period.

Combining the above factors, the GTFP was measured. Referring to the Classification and Code of Coastal Administrative Areas (HY/T094-2006), the 11 coastal provinces are divided into the areas of Bohai rim, the East China Sea, and the South China Sea. Among them, the Bohai rim area includes Tianjin, Hebei, Liaoning, and Shandong. The area of East China Sea includes Shanghai, Jiangsu, and Zhejiang. The area of South China Sea includes Fujian, Guangdong, Guangxi, and Hainan.

Table 2 gives the basic characteristics of the input and output indicator data. The ratio of the maximum and minimum capital input is 75.08, and the mean value of capital input exceeds the median; the ratio of maximum to minimum labor input is about 11.05, which is the smallest of several other inputs, and the standard deviation and median of the three resource input indicators are very different. It can be seen that the difference between provinces in capital input is large, material capital input shows path dependence, and the capital stock of large provinces have absorbed and accumulated more capital, resulting in the phenomenon of factor aggregation; in recent years, the mobility of the labor force between provinces is large, the distribution of labor input between provinces is relatively small, but there is still a certain gap between the quality and skill level of the labor force in different provinces; the marine economic development of each province is highly dependent on resources, but the distribution is more scattered. From the output point of view, the maximum desirable output is close to 40 times the minimum value, the scale and speed of inter-provincial marine economic growth are very different, and the maximum desirable output is also dozens of times the minimum, reflecting that the marine economic development of many provinces is at the expense of the environment, and China's marine environmental efficiency still needs to be improved.

Table 2. Descriptive statistics for the main indicators.

Indicator	Variable	Units	Mean	Std. Dev	Median	Min	Max	Number of Samples
Desirable output	GOP	RMB 100 million	3644.188	232.584	2936.054	300.700	12,026.370	143
Resource input	Number of travel agencies in coastal areas		1141.350	54.585	1116	147	2872	143
	Pier length	m	57,312.350	3496.883	48426	5355	176,208	143
	Area of use in the sea	hectares	23,634.275	3038.834	6150	12.800	173,633.800	143
Labor input	Number of people involved in the sea	ten thousand	309.9302	17.8635	209.8000	81.5000	900.5944	143
Capital investment	Marine capital stock	RMB 100 million	9480.742	613.359	8297.697	475.508	35,703.378	143
Undesirable output	Marine wastewater	tons	16,263.927	945.964	13,075.339	1090.931	43,807.600	143
	Marine exhaust gas	100 million cubic meters	3764.741	211.642	3639.371	254.560	14,402.058	143
	Marine solid waste	tons	0.359	0.069	0.019	0	5.232	143

3. Results

3.1. Dynamic Evolution of GTFP and Decomposition Components

Based on input and output data for China's coastal areas from 2006 to 2018, the ML index, reflecting the changes of GTFP in each province, was calculated by MAXDEA software, and the ML index was broken down into the TC index and EC index. The trend over the same period for each index is shown in Figure 4. It is not difficult to see that the overall ocean GTFP is in a state of steady growth. The TC index is more in line with the ML index for each year, while the EC index is close to one in most years, indicating that technological progress in marine development has a stable effect on the growth of ocean GTFP, while the change of technical efficiency has no significant effect on GTFP.

The TC index can be further broken down into IBTC, OBTC, and MATC indices. The MATC index is less than the TC index in each year, indicating that the efficiency of the technology scale has not played a positive role in technological progress, possibly because the imbalance of the development of marine industry limits the efficiency of the technology scale. When compared with the IBTC index, the curve trend of the OBTC index is highly compatible with the TC curve, indicating that technological progress is not neutral, and that output bias is closely related to the change of technological progress.

Figure 5 shows more clearly the movement of the OBTC index and the ML index over the same period. The OBTC index and the ML index have a certain consistency of the trend of change, indicating that the output-biased technological progress has a significant impact on the ocean GTFP. The two indices fluctuated significantly between 2008 and 2012. However, 2012 was a turning point, since after a short period of small fluctuations, the two indices improved after 2013 and the volatility trend was more stable. From the perspective of the size of the index, there is still a lot of room for progress in the adaptive and technological diffusion of China's marine economic development.

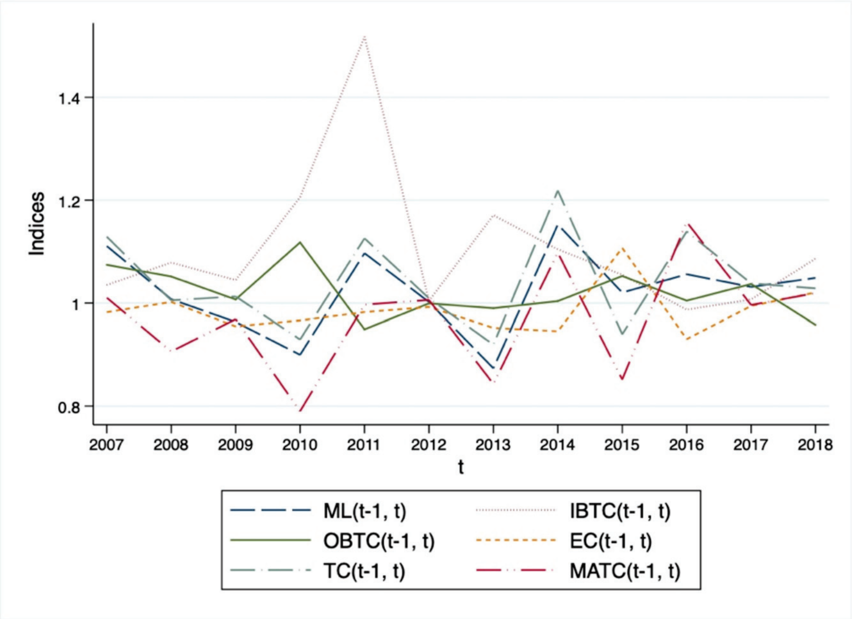

Figure 4. The average annual trend of GTFP and its decomposition indices.

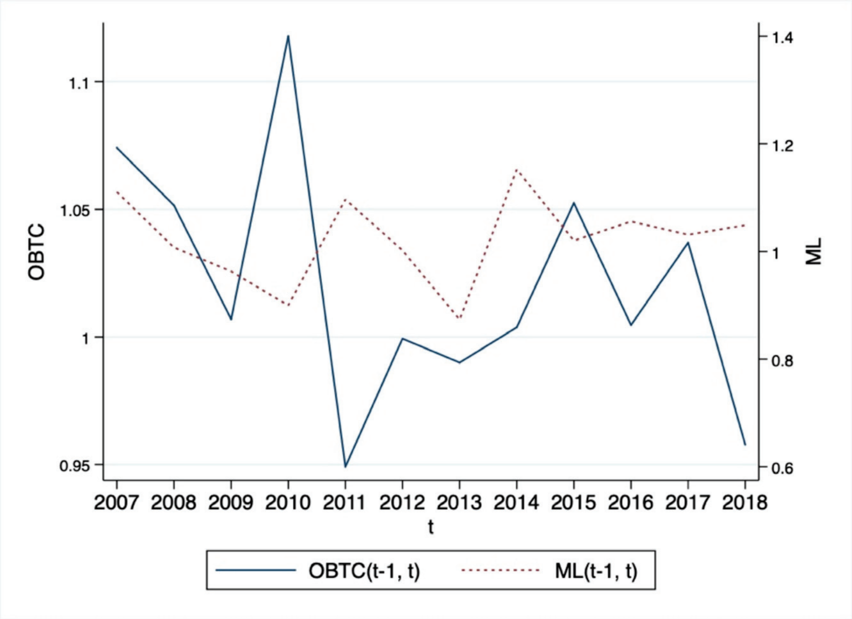

Figure 5. Trends in the OBTC and ML indices.

3.2. Regional Distribution of the Marine Green OBTC Index

Figure 6 reflects the OBTC index and trends in the three regions around 2012. It can be seen that after 2012, the OBTC index of the Bohai rim area had increased, while the OBTC index of the East China Sea area and the South China Sea area had decreased slightly, but the value of the OBTC Index in most regions is greater than one, which shows that the closely introduced marine environmental protection policy effectively corrects the negative externalities of marine production, constrains the relevant practitioners to carry out green production, technological innovation, and industrial restructuring, and forms a win–win situation of ecological and economic common development. Among them, the OBTC index of the East China Sea area is higher than that of the Bohai rim area and the South China Sea area. It is basically in line with the current situation of marine economic development in various regions. In contrast, the OBTC index in the South China Sea area is the lowest.

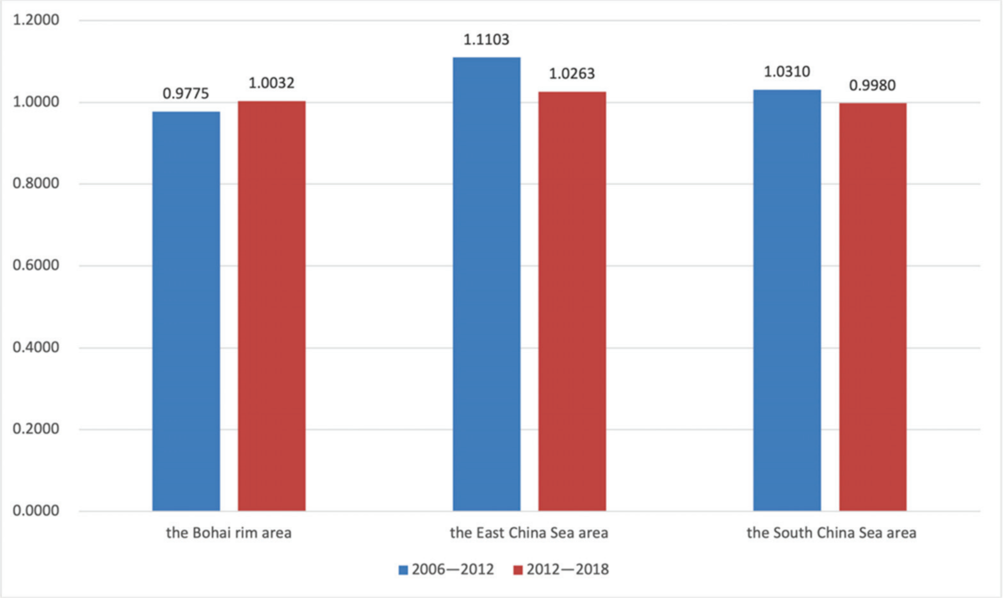

Figure 6. Changes in the OBTC index for different regions over time periods.

Table 3 shows the cumulative changes in the Marine Economic ML index and OBTC index in different coastal provinces of China from 2006 to 2018, represented by their respective averages. During the sample period, the ML and OBTC indices were consistently between [0.9368, 1.2017] and were generally stable. On average, in coastal areas, the ML and OBTC indices grew steadily at 2.19% and 2.04%, respectively, reflecting the fact that the output bias of current technological progress has overall supported the growth of the marine economy. Six of the nine provinces have an ML index greater than one, indicating that the ocean GTFP is on the rise in most areas.

Table 3. ML and OBTC indices for each province.

Region	Province	ML	OBTC
Bohai rim area	Tianjin	1.0802	1.0156
	Hebei	0.9940	1.0076
	Liaoning	1.0513	1.0020
	Shandong	0.9368	0.9364
East China Sea area	Shanghai	1.1943	1.2017
	Jiangsu	1.0106	1.0025
	Zhejiang	1.0085	1.0006
South China Sea area	Fujian	1.0030	1.0044
	Guangdong	0.9871	1.0105
	Guangxi	0.9803	1.0086
	Hainan	0.9948	1.0345
Average for coastal areas		1.0219	1.02039

Judging from the index vibration range, the imbalance in the development of the regional marine economy is significant. The Shandong ML and OBTC indices fell the most, by an average of about 6.32 and 6.36% per year, indicating that the OBTC in Shandong has not played a significant economic promotion role. In addition, Hebei, Guangdong, Guangxi, and Hainan also saw small declines. However, the ML and OBTC indices in Shanghai rose the most. They grew at a rate of about 19.43 and 20.17% per year, respectively. Both are at the highest level in the coastal areas. This was followed by Tianjin and Liaoning. In addition, Jiangsu, Zhejiang, and Fujian provinces have seen small increases, indicating that these provinces can still achieve efficient green marine growth through rational adjustment of pollution control, while achieving a steady annual growth rate of 5.8%. From these data, it is also sufficient to see that the OBTC and GTFP changes have a certain consistency.

3.3. Analysis of Specific Output Biases for Technological Progress

The measurement of the OBTC index reflects the existence of output-biased technological progress, and whether the OBTC index has contributed to the growth of GTFP. Next, this paper further analyzed the rationality of the existing bias, that is, to determine whether China's marine technology is biased towards reducing marine environmental pollution and whether marine development conforms to the concept of green environmental protection. Based on the output bias judgment method proposed in Section 2.2.4, we calculated the intertemporal ratio of the expected output indicator to the undesirable output indicator. Next, we combined it with the OBTC index to identify the output bias of marine technology progress in each province, in each year, and analyzed its change law.

Figure 7 shows the trend in the number of provinces where marine technology is biased towards reducing marine waste in 2006–2018, which reflects the degree of green bias in marine economic development over the years. During the study period, the number of provinces whose marine output was biased towards reducing pollutant emissions increased. Around 2008 and 2013, the degree of green bias in marine economic development was under market and policy pressures, respectively. The former was negatively affected by the macro economic crisis, while the latter was due to 2012 as an inflection point, and the Report stressed the construction policy of the maritime power strategy in a short period of time after the implementation of the policy to balance the use of resources and the ecological environment protections, hence the marine environment appears as short-term fluctuations. Since then, however, the degree of marine green bias has increased significantly since 2014, reflecting the vulnerability and sensitivity of the marine environment.

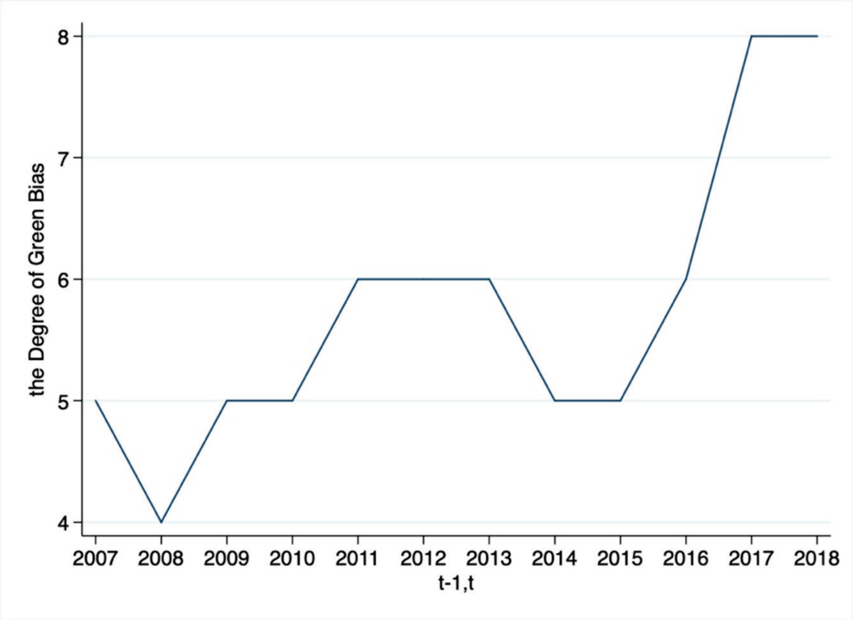

Figure 7. Number of provinces in which OBTC trends towards reducing pollutant emissions in each year.

Table 4 shows changes in output bias for 2006–2018. As can be seen, 8 of the 12 time periods were biased towards increased marine pollution and only four were biased towards increased desirable output.

Table 4. Output bias over time.

Year	OBTC	MRT$_{bg}$	Bias
2006–2007	1.0741	0.8088	Y_b
2007–2008	1.0515	0.8596	Y_b
2008–2009	1.0069	0.8915	Y_b
2009–2010	1.1178	0.8625	Y_b
2010–2011	0.9491	0.9901	Y_g
2011–2012	0.9994	0.8627	Y_g
2012–2013	0.9900	0.9098	Y_g
2013–2014	1.0038	0.8976	Y_b
2014–2015	1.0525	0.9517	Y_b
2015–2016	1.0047	0.7971	Y_b
2016–2017	1.0370	0.9708	Y_b
2017–2018	0.9578	0.9659	Y_g

Table 5 provides a visual indication of the bias of output-biased technological progress in different regions towards different outputs, with data showing the average of the indices divided over a three-year period in each coastal province. It can be seen from the data comparison that overall output-biased technological progress tends to increase environmental pollution rather than increase desirable output. However, there has been a marked increase in green bias nationwide in 2015–2018, which is consistent with the time trend characteristics of output bias. Specific to the provinces, it can be found that in recent years, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, and Hainan have paid more attention to the improvement of the quality of the marine environment. In contrast, Tianjin, Hebei, and Guangxi have been more inclined to increase total factor productivity and boost marine economic growth by emitting more pollutants. From the perspective of time, the output bias after 2012 is driven in the direction of Y_g.

Table 5. Regional output bias.

	2006–2009			2009–2012			2012–2015			2015–2018		
	OBTC	**MRT$_{bg}$**	**Bias**	**OBTC**	**MRT$_{bg}$**	**Bias**	**OBTC**	**MRT$_{bg}$**	**Bias**	**OBTC**	**MRT$_{bg}$**	**Bias**
Tianjin	1.0059	0.8079	Y_b	1.0267	0.9885	Y_b	1.0081	0.9020	Y_b	1.0215	0.9855	Y_b
Hebei	1.0091	0.8143	Y_b	1.0212	0.6070	Y_b	1.0002	0.9857	Y_b	1.0001	0.9313	Y_b
Liaoning	0.9964	0.5983	Y_g	1.0113	1.2654	Y_g	1.0002	0.9415	Y_b	0.9999	0.6181	Y_g
Shanghai	1.2971	0.7471	Y_b	1.3588	1.0597	Y_g	1.1916	0.8679	Y_b	0.9592	0.8785	Y_g
Jiangsu	1.0032	0.9603	Y_b	1.0032	0.9651	Y_b	1.0094	0.9153	Y_b	0.9941	0.8435	Y_g
Zhejiang	0.9974	0.8553	Y_g	1.0018	0.8672	Y_b	1.0034	0.8726	Y_b	0.9999	0.8799	Y_g
Fujian	1.0002	0.9090	Y_b	1.0054	0.7197	Y_b	1.0102	0.9334	Y_b	1.0016	1.1875	Y_g
Shandong	1.0150	0.9765	Y_b	0.7346	0.9567	Y_g	0.9963	0.9869	Y_g	0.9996	0.9253	Y_g
Guangdong	1.0791	0.9579	Y_b	0.9958	0.7444	Y_g	0.9767	0.8687	Y_g	0.9903	0.9065	Y_g
Guangxi	1.0000	0.7819	Y_g	1.0073	0.6040	Y_b	1.0001	0.8048	Y_b	1.0270	0.8642	Y_b
Hainan	1.0829	0.9775	Y_b	1.0771	1.1786	Y_g	0.9733	1.0380	Y_b	1.0046	1.0039	Y_g
All	1.0442	0.8533	Y_b	1.0221	0.9051	Y_b	1.0154	0.9197	Y_b	0.9998	0.9113	Y_g

Table 6 shows the proportion of provinces in various regions that have been biased towards reducing marine pollutant emissions as a percentage of the total number of provinces in the region. Between 2006 and 2018, technological progress in most provinces of the East China Sea area and the South China Sea area tended to reduce pollutant emissions, while the Bohai rim area tended to increase the total output value. After 2012, the degree of green bias in various regions has improved significantly.

Table 6. Percentage of provinces in different regions where technological progress tends to the reduction of undesirable output over time.

Region	Percentage of Provinces in Each Region over the Period Where OBTC Tend to Reduce Pollutant Emissions (%)		
	2006–2018	2006–2012	2012–2018
Bohai rim area	41.67	37.5	45.83
East China Sea area	63.88	61.11	66.67
South China Sea area	54.17	45.83	62.5

Specifically, the green bias of the marine economy in the East China Sea area is the highest, and the OBTC index is also the highest. In contrast, the green bias degree and OBTC index of the Bohai rim area are the lowest, but in recent years, its ML index, OBTC index, and green bias degree rose step by step. However, the area of South China Sea's green bias increased significantly in 2012–2018, while its OBTC index declined during that period.

4. Discussion

4.1. Analysis of the Existence and Trend of Output-Biased Technological Progress

From the dynamic evolution and regional differences of the OBTC index, there is obvious output-biased technological progress in the development process of China's marine economy, and its change trend is highly consistent with GTFP, indicating that the changes between the two have a strong correlation.

As far as the time change of OBTC index is concerned, 2008 was negatively affected by the macro economy, resulting in a decline in the efficiency of the marine economy, and in the early stage of the development of the marine economy, resource constraints and environmental pollution also caused a certain degree of efficiency loss. However, in the Report of 2012, the requirements for marine ecological protection were clearly emphasized, and since then, the national governments at all levels have formulated corresponding policies in response to the national strategy, but the marine economic development has a certain period of adaptation to the implementation of the policy. Subsequently, the two indices stabilized, reflecting that the marine macro policy can improve the marine environment and stabilize the marine economic development.

From the perspective of the regional differences of the OBTC index, the index is from high to low in the East China Sea, the Bohai rim, and the South China Sea area. The reason for this is that the East China Sea area has sufficient funds and human resources into marine science and technology and production, which is conducive to the improvement of the marine economy. As far as the area of South China Sea is concerned, although the marine economy of Guangdong and Fujian is relatively developed, the marine economy of Guangxi and Hainan is not very good. Without sufficient funds and human resources, the innovation capacity of marine science and technology is relatively low, and the effectiveness of marine economic technology is low.

Specifically, from each province, the impact of the OBTC index on the development of the marine economy varies from region to region. Among them, the higher indices of Shanghai are related to its strong capital and higher-level talent pool, while the decline of Shandong's indices are large. Perhaps, due to the diminishing marginal return of marine scientific and technological output and the low effective conversion rate of related achievements, the promotion effect on GTFP is not fully reflected.

4.2. The Role of Technological Progress in Promoting the Bias of Green Output

Judging from the time fluctuation trend of green output bias, in the process of reducing marine pollution, there is constant pressure from the production model of sacrificing the environment in exchange for the increase in marine GDP, but the marine environmental protection policies generally guarantee the green development of the ocean. When combining it with the output bias of Table 4, although the degree of marine green bias has increased significantly in recent years, the marine environmental protection in the coastal provinces is still relatively weak, and the overall trend is still biased towards more extensive growth.

From the perspective of regional differences, the degree of green output bias of technological progress in coastal provinces is obviously different. Among them, Guangxi's OBTC and MRT_{bg} indices have a large gap in each period, which is because Guangxi has undertaken many industrial transfers, with serious pollution and high emissions. The low level of marine industrial structure, the high energy consumption of economic output, and the extensive development mode [49] have led to a weak foundation of the province and a lower marine economic output value than the national average, which ultimately aggravates the contradiction between Guangxi's marine economic development and the improvement of marine environmental quality.

When combining the dynamic data of different periods with the realistic background, the 2012 Report put forward new requirements for marine economic development, and local governments have formulated corresponding policies in response to national strategies. Since the formulation and implementation of policies often have a certain lag [50], after a short-term policy adjustment, in recent years, as well as the continuous progress, diffusion and innovation of modern technological levels, the marine economy has developed in the direction of increasing the desired output and reducing pollution emissions, and the national marine environmental governance policy has achieved results.

Judging from the changes in the proportion of provinces in various areas to reduce pollutant emissions, China's coastal areas have achieved certain results in rationally utilizing marine resources and controlling pollution emissions. Overall, however, there is still much room for improvement in the number of provinces in various regions that are biased towards protecting the environment. Among them, the degree of green output bias from high to low is the East China Sea, the South China Sea, and the Bohai rim area, but the Bohai rim area has risen significantly in recent years. It shows that the East China Sea region has effectively coordinated the relationship between the growth of marine economic output value and environmental protection, while the coordination of the two in the South China Sea region needs to be strengthened. However, in the early stage of the development of the marine economy, the Bohai rim area has paid too much attention to the improvement of the total marine output value and ignored the protection of the marine environment, but the increase in their green bias of its output in the later period gradually played a leading role in its economic growth, and the overall environmental protection measures in the region still need to be further strengthened.

In summary, this paper discusses the dynamic link between technological progress and the bias of green output in China's marine economy. In the follow-up study, we will further conduct a detailed quantitative analysis of the degree of green bias, and analyze the factors that affect the green output bias of marine technology progress, to make more targeted suggestions for the green development of the marine economy.

5. Conclusions

The novelty of this study is that the green development of the marine economy was discussed from the perspective of output, and the OBTC index of each region in each year was calculated to determine whether there is a significant output-biased technological progress in the development of China's marine economy. Furthermore, we studied the rationality of the current output-biased technological progress, intuitively reflected the differences in the degree of green bias in coastal areas, and discussed whether technological progress has promoted the green output bias of the marine economy, that is, to determine whether China's marine economy has developed in the direction of increasing the desirable output and reducing the undesirable output.

The results show that there is obvious output-biased technological progress in China's marine economy, and this output-biased technological progress has led to the improvement of GTFP. During the sample period, although most of China's coastal areas in general still tend to pursue the improvement of the total output value of the marine economy at the expense of the environment, the green bias has improved significantly after 2015, driven by the active policies of the relevant marine environment protection. It shows that technological progress has increased the bias of green output in the marine economy. From the perspective of different areas, the imbalance in the development of the regional marine economy is significant. The East China Sea area has the highest green bias, while the Bohai rim area has the lowest. However, the coordination between the development of the green marine economy and environmental protection in the South China Sea area needs to be improved.

To achieve sustainable development of the marine economy, coastal areas should control undesirable output as much as possible. Overall, all regions should try to avoid the negative externalities caused by environmental pollution and improve the level of green output. In view of the different areas, relevant departments should formulate differentiated management policies according to the specific situation in each region. Among them, we should pay attention to the environmental protection of the Bohai rim area, the comprehensive strength of green marine development in the South China Sea area, and the efficiency of green marine output in the East China Sea area. In this way, it will promote the coordinated development of the interregional marine economy.

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Article

Spatio-Temporal Disparities of Mariculture Area Production Efficiency Considering Undesirable Output: A Case Study of China's East Coast

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Abstract: Mariculture areas are an important non-renewable natural resource and continuously improving their efficiency is important for increasing mariculture output and adjusting its structure. The aim of this study was to measure the mariculture area production efficiency (MAPE) considering undesirable outputs, further analyze its spatiotemporal disparities, and analyze the reasons for the differences observed during the period from 2008 to 2019. The super-efficiency Engel–Blackwell–Miniard (S-EBM) model and global Malmquist–Luenberger (GML) index was selected to analyze the technical efficiency and productivity of MAPE from both the static and dynamic aspects, and the Theil index was used to decompose the regional differences. The results showed that the MAPE showed fluctuation and an increasing trend overall; the production efficiency and technical progress showed a fluctuating rising trend, and technical progress had a significant driving effect on the production efficiency; and intra-regional differences were the main factors that cause the differences in MAPE. The findings suggest the increase of scientific and technological investment in mariculture, changes in mariculture methods, the establishment of environmental monitoring centers in mariculture areas, and the sharing of information technology between regions to achieve sustainable development.

Keywords: global Malmquist–Luenberger index; mariculture area production efficiency; spatiotemporal disparities; super-efficiency EBM model; Theil index

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1. Introduction

The ocean is a major component of the global life support system and a valuable resource that helps to achieve the sustainable development of human society [1]. With the rapid increase of the global population, environmental pollution, and shortages of resources, food problems are becoming increasingly serious [2,3]. Due to economic development and the improvement of living standards, people are not satisfied with merely solving the problem of food quantity, but are also paying more attention to the pursuit of high-quality food [4,5]. Therefore, many coastal countries have focused their strategic vision on the ocean, and protein extraction from the ocean has become a hot industry in relation to solving food security issues at present and in the future [6]. According to the Global Aquaculture Production database, the global mariculture production in 2019 reached 57,872.179 kilotons. Although the current growth rate has slowed down, production has always maintained a growth trend. The mariculture production in China ranks first in the world and is developing rapidly, increasing from 10 kilotons in 1950 to 36,403.631 kilotons in 2019, accounting for 3.17% and 62.9% of the world's mariculture production, respectively. Therefore, as a powerful mariculture country, China's research on mariculture is of great significance, and can provide guidance and reference for other coastal countries or regions to develop and utilize mariculture sea areas.

In recent years, China's mariculture is facing severe challenges; for instance, the overall mariculture area has decreased year by year, and the ecological environmental pollution in mariculture areas has become increasingly serious [7]. According to the Report on the State of the Fishery Eco-Environment in China, from 2015 to 2018, the emissions of the major mariculture areas in China exceeded standards to a large extent, with inorganic nitrogen and active phosphate exceeding 52% in the detected area [8]. This development reduces the productivity of polluted sea areas and also affects the sustainable development of mariculture. In this context, continuously improving mariculture area production efficiency (MAPE) has become the key to increasing mariculture production and ensuring food security under the constraints of the marine ecological environment.

As the world's attention to the ocean increases, China is also paying more and more attention to ocean research [9–13], and relevant studies have been conducted from the perspective of mariculture areas [14,15]. A mariculture area is defined as a non-renewable key resource element for mariculture and seafood production is similar to grain production [16]. That is, grain is produced using cultivated land resources, whereas seafood is produced using mariculture areas. The mariculture area is equivalent to the cultivated land in grain production, and the production processes are similar. China is a country with a large population, and since ancient times, agriculture has been the foundation of the country [17,18]. China's cultivated land research has been more in-depth [19–21], and relatively speaking, the number of specific studies on mariculture areas is relatively small, and the research content relating to the ocean primarily focuses on the entire marine economy or marine industry [22–25]. Collectively, these studies put more emphasis on the importance of cultivated land development and utilization, and the whole sea area, but no previous study has considered the use of mariculture sea areas from the perspective of sea area resources.

Therefore, to fill the knowledge gap noted above, China's east coast was selected as the study area in this research to evaluate the MAPE of China from 2008 to 2019 and further explore its temporal and spatial disparities. This study is based on the existing research methods, considering the undesirable output of mariculture areas, which is a multi-output situation, using the super-efficiency Engel–Blackwell–Miniard (S-EBM) model and the global Malmquist–Luenberger (GML) index to measure and analyze the technical efficiency and productivity of MAPE from both the static and dynamic perspectives. The main aims of this study were to measure the MAPE, to further analyze its temporal and spatial differences, and to analyze the reasons for the differences through the Theil index. The results of this research will be helpful for improving the production efficiency and realizing the voluntary and sustainable development of mariculture areas, and may provide guidance for the development and utilization of sea areas and relevant decision-making.

The remainder of this paper is organized as follows. In Section 2, we briefly review the existing literature on mariculture, focusing on production efficiency and methods. Section 3 introduces the methodology used for evaluating and analyzing MAPE. Section 4 presents the input and output indicators, as well as the data processing methods. The results of the empirical study on the China's east coast MAPE over 2008–2019 are presented in Section 5, followed by the conclusions and discussion in Section 6.

2. Literature Review

2.1. Research on Mariculture

The research literature on mariculture mainly focuses on mariculture development, policy, efficiency evaluation, etc. Salayo et al. [26] defined mariculture in the Philippines as the cultivation of finfish, shellfish, seaweed, and other commodities in cages, pens, stakes, and rafts in the marine environment and assessed the biophysical and socio-economic background of mariculture. Yu et al. [6] analyzed the evolution of China's mariculture policy and divided it into three stages: the mariculture production period, mariculture integrated management period, and mariculture sustainable development period, and analyzed the characteristics of the evolution of China's mariculture policy accordingly. Yu et al. [27] used a measurement model based on over-relaxation and the GML index to measure the mariculture efficiency scores and their changes in nine coastal provinces of China from 2004 to 2016, and found that the efficiency of mariculture had increased by 6.45% from 2004 to 2016, and technological progress was the main driving force.

2.2. Research on Methods of Efficiency

Efficiency evaluation methods are a hot topic in the efficiency field and there are generally three methods for measuring efficiency: the single-index method [28,29], stochastic frontier analysis (SFA) [30,31], and data envelope analysis (DEA) [32–35]. Since DEA and SFA methods are currently used more commonly, the following literature mainly focus on efficiency evaluation approaches using these two methods.

The SFA method uses the construction of a production function to construct the production frontier and the deviation is decomposed into technical inefficiency and random error [36]. The result is less affected by the specific features of the sample and is more reliable and stable. In recent years, SFA has become popular in efficiency evaluation. Shabanzadeh-Khoshrody et al. [37] used the Tornqvists–Theil (TTP) index, SFA, and the matching method to analyze the effects of the Baft dam construction on the efficiency and productivity of downstream agricultural land. Van Nguyen et al. [38] examined the sensitivity of technical and scale efficiency estimates in stochastic frontier analysis, using data from an Australian fishery. Wang et al. [39] used the SFA model to evaluate the performance of soil and water conservation in consideration of changes in local environmental managers.

Different from the SFA parameter method, DEA is a non-parametric evaluation method, and the DEA method is mature in the study of efficiency measurement. Wang et al. [40] constructed a fully fuzzy DEA and used the large datasets of 264 Chinese cities over 2009–2018 to evaluate the urban circular economy. Some scholars have begun to pay attention to the spatiotemporal differences in production efficiency [41–43]. Given the increasingly severe environmental problems, some scholars have begun to focus on undesirable outputs [44–46]. Wang et al. [47] used the DEA model to calculate the ecological efficiency of China, considering undesirable outputs. Saber et al. [48] calculated the eco-efficiency for each of four impact categories (i.e., terrestrial, freshwater, and marine ecosystems, as well as human health) and analyzed differences in eco-efficiency between 200 paddy farms in Iran. Nabavi-Pelesaraei et al. [49] used the method of life cycle assessment (LCA) and DEA to measure the environmental efficiency of different systems and evaluated the possibility of the application of solar energy technology in the production of sunflower oil in Iran.

2.3. Research on Efficiency Measurements of Mariculture

From the perspective of efficiency measurements of mariculture, some scholars have used different methods to study this field. Singh et al. [50] used SFA to study the economic efficiency of aquaculture in southern Tripura. Nielsen et al. [51] used DEA to analyze the impact of the new environmental water purification system on the efficiency of freshwater aquaculture in Denmark. Ji et al. [52] and Wang et al. [53] used the economic loss of pollution as an undesired output and a DEA model to measure the efficiency of aquaculture and the mariculture industry in China. Vassdal et al. [54] used the Malmquist productivity index to measure the total factor productivity (TFP) of the marine salmon produced in Norway.

2.4. Literature Summary

At present, the efficiency evaluation of mariculture is a research hotspot, and there are several studies available for research. We classify and summarize these literatures and present a table summarizing the related studies (Table 1). Although the efficiency of mariculture has been studied, the production efficiency of the aquaculture area has not been explored to a large extent, and there is still a lack of comprehensive and effective evaluations. Mariculture research mainly focuses on qualitative analysis, whereas quantitative analysis on production efficiency measurement is rare. The methods used in these studies are singular, and previous studies have not considered the combination of static and dynamic methods when comprehensively considering environmental constraints. Thus, it is urgently required to develop a method for MAPE.

Table 1. Summary of the related studies.

Field	Content	Example	Year	Contribution
Mariculture	Development	Salayo et al. [26]	2012	Assessed the biophysical and socio-economic background of mariculture.
	Policy	Yu et al. [6]	2020	Analyzed the evolution of China's mariculture policy, and divided it into three stages.
	Efficiency	Yu et al. [27]	2020	Measured the mariculture efficiency scores and their changes in nine coastal provinces of China.
Methods of efficiency	SFA	Shabanzadeh-Khoshrody et al. [37]	2016	Analyzed the effects of the Baft dam construction on the efficiency and productivity of downstream agricultural land.
		Van Nguyen et al. [38]	2021	Examined the sensitivity of technical and scale efficiency estimates in stochastic frontier analysis.
		Wang et al. [39]	2022	Evaluated the performance of soil and water conservation.
	DEA	Wang et al. [40]	2021	Evaluated the urban circular economy.
		Wang et al. [47]	2020	Calculated the ecological efficiency of China considering the undesirable output.
		Saber et al. [48]	2021	Calculated the eco-efficiency for each of four impact categories.
		Nabavi-Pelesaraei et al. [49]	2021	Measured the environmental efficiency of different systems.
Efficiency measurement of mariculture	SFA	Singh et al. [50]	2008	Studied the economic efficiency of aquaculture in southern Tripura.
	DEA	Nielsen et al. [51]	2011	Analyzed the impact of the new environmental water purification system on the efficiency of freshwater aquaculture in Denmark.
		Ji et al. [52]	2015	Measured the efficiency of aquaculture.
		Wang et al. [53]	2017	Measured mariculture industry in China.
		Vassdal et al. [54]	2011	Measured the TFP of the marine salmon produced in Norway.

3. Materials and Methods

3.1. The S-EBM Model with Consideration of Undesirable Outputs

Currently, the methods for measuring efficiency primarily include SFA and DEA. The SFA model considers the effect of random errors on efficiency but relies on stricter assumptions and is mainly applicable to multiple inputs and single outputs. The DEA model is a non-parametric method that calculates the relative efficiency of a decision-making unit (DMU) by constructing the production frontier of the data and is the most commonly used among the two methods [55]. The traditional DEA model considers only the radial distance and ignores the influence of slack variables; therefore, it cannot measure efficiency by additionally considering undesirable outputs accurately [56]. In response to this problem, Tone [57] proposed the slacks-based measure (SBM) model, which takes into account the effects of slack variables on efficiency measurements, while avoiding the deviation caused by the difference in radial and angle distances and solving the high efficiency problem of the traditional DEA estimation approach. A disadvantage of this method is that it cannot handle a situation in which the input and output are both radial and non-radial. The Engel–Blackwell–Miniard (EBM) model was developed based on this model and can handle mixed radial situations (both radial and non-radial values) and calculate the non-radial values of inputs and outputs [58].

When the DEA model is used for analysis, there are often multiple DMUs that are evaluated as effective. Especially when the number of input and output indicators is large, the number of effective DMUs will increase. In the traditional DEA model, the maximum efficiency value is 1. At this point, the effective DMU efficiency value is equal, and it is difficult to further distinguish the level of DMU efficiency value. In order to solve this problem, Andersen et al. proposed a “super-efficiency model”, which can eliminate the evaluated DMU from the reference set, so the efficiency value of the evaluated DMU is obtained by referring to the frontier of the other DMU [59]. The effective DMU value is generally greater than 1, so the effective DMU can be distinguished. Therefore, in this paper we use the S-EBM model to measure the MAPE.

Taking provinces as DMUs, in this study we construct the set of production possibilities for MAPE, as shown in formula (1). Assuming that there are t periods $(t = 1, \cdots, T)$ and n DMUs $(n = 1, \cdots, N)$, each DMU has m $(m = 1, \cdots, M)$, j $(j = 1, \cdots, J)$ and p $(p = 1, \cdots, P)$ species of the input x_m, the desirable output y_j and the undesirable output b_p, respectively. In Formula (1), λ is the weight of each DMU in establishing the set of production possibilities.

$$P = \left\{ \begin{array}{l} (x^t, y^t, b^t) \left| \sum\limits_{t=1}^{T} \sum\limits_{n=1}^{N} x^t_{nm}\lambda^t_n \le x^t_m; \sum\limits_{t=1}^{T} \sum\limits_{n=1}^{N} y^t_{nj}\lambda^t_n \le y^t_j; \sum\limits_{t=1}^{T} \sum\limits_{n=1}^{N} b^t_{np}\lambda^t_n \le b^t_p; \right. \\ \qquad \sum\limits_{t=1}^{T} \sum\limits_{n=1}^{N} \lambda^t_n = 1; \lambda \ge 0 \end{array} \right\} \tag{1}$$

On this basis, the S-EBM model is constructed, and the model is expressed as follows [60]:

$$\begin{array}{rl} \gamma^* & = \min\limits_{\theta,\eta,\lambda,s^-,s^+} \dfrac{\theta - \varepsilon_x \sum\limits_{m=1}^{M} \dfrac{\omega^-_m s^-_m}{x_{km}}}{\varphi + \varepsilon_y \sum\limits_{j=1}^{J} \dfrac{\omega^+_j s^+_j}{y_{kj}} + \varepsilon_b \sum\limits_{p=1}^{P} \dfrac{\omega^{b-}_p s^{b-}_p}{b_{pk}}} \\ s.t. & \sum\limits_{t=1}^{T} \sum\limits_{n=1}^{N} x^t_{nm}\lambda^t_n + s^-_m = \theta x_{km}, m = 1, \ldots, M \\ & \sum\limits_{t=1}^{T} \sum\limits_{n=1}^{N} y^t_{nj}\lambda^t_n - s^+_j = \varphi y_{kj}, j = 1, \ldots, J \\ & \sum\limits_{t=1}^{T} \sum\limits_{n=1}^{N} b^t_{np}\lambda^t_n + s^{b-}_j = \varphi b_{kp}, p = 1, \ldots, P \\ & \sum\limits_{t=1}^{T} \sum\limits_{n=1}^{N} \lambda_1 + \lambda_2 + \ldots + \lambda_n = 1 \\ & \lambda \ge 0, s^- \ge 0, s^+ \ge 0 \end{array} \tag{2}$$

where γ^* is the objective function and k is the number of DMUs; m, n, and b represent the number of inputs, desirable outputs, and undesirable outputs, respectively; s^-_m, s^+_j, and s^{b-}_p represent the slack variables of inputs, desirable outputs, and undesirable outputs, respectively; ω^-_m, ω^+_j, and ω^{b-}_p represent the weights of input indicators, desirable outputs, and undesirable outputs, respectively; θ is the planning parameter of the radial part; and ε_x is the key parameter.

3.2. GML Index

The S-EBM model proposed in this study can measure the MAPE and perform static analysis; however, it cannot measure the trend change of the efficiency value in the time series and cannot perform dynamic analysis [61]. However, the GML index is an improvement of the traditional Malmquist–Luenberger index, which makes it possible to compare the efficiency across time periods and can make up for the defects of the S-EBM model [62,63]. The GML index belongs to dynamic analysis, which can analyze the changes in TFP and the effects of technical efficiency and technological progress. Therefore, in this study we combine it with the GML index analysis method to analyze the production efficiency in different years. Therefore, based on the static analysis of MAPE conducted using the S-EBM model, in this study we further use the GML index to dynamically analyze the TFP of MAPE for different years. The GML index from period t to period $t+1$ is expressed as follows:

$$\begin{aligned} \mathrm{GML}_{t+1}^{t} \quad & (x^t, y^t, b^t, x^{t+1}, y^{t+1}, b^{t+1}) = \frac{1+\theta^G(x^t, y^t, b^t)}{1+\theta^G(x^{t+1}, y^{t+1}, b^{t+1})} \\ & = \frac{1+\theta^t(x^t, y^t, b^t)}{1+\theta^{t+1}(x^{t+1}, y^{t+1}, b^{t+1})} \times \left[\frac{1+\theta^G(x^t, y^t, b^t)}{1+\theta^t(x^t, y^t, b^t)} \times \frac{1+\theta^{t+1}(x^{t+1}, y^{t+1}, b^{t+1})}{1+\theta^G(x^{t+1}, y^{t+1}, b^{t+1})} \right] \\ & = \mathrm{GMLEC}_{t+1}^{t} \times \mathrm{GMLTC}_{t+1}^{t} \end{aligned} \tag{3}$$

where GML_{t+1}^{t}, GMLEC_{t+1}^{t}, and GMLTC_{t+1}^{t} represent the changes in input-output efficiency, technical efficiency, and technical progress from period t to period $t+1$, respectively. A GML_{t+1}^{t} value above 1 indicates an increase in production efficiency, and a decrease in efficiency otherwise.

3.3. Theil Index

The Theil index is an important method for measuring regional differences. It can decompose regional differences into intra- and inter-regional differences and measure the contribution rate of the two differences to the overall difference. Therefore, it not only reflects the evolution process of intra- and inter-regional differences, but also the main factors that cause the total difference [64]. The formulas are as follows:

$$T = \sum_i \left(\frac{C_i}{C}\right) \ln\left(\frac{C_i/C}{X_i/X}\right) \tag{4}$$

$$T_w = \sum_j \left(\frac{C_j}{C}\right) T_{wi} = \sum_j \sum_i \left(\frac{C_j}{C}\right)\left(\frac{C_{ji}}{C_j}\right) \ln\left(\frac{C_{ji}/C_j}{X_{ji}/X_j}\right) \tag{5}$$

$$T_b = \sum_j \left(\frac{C_j}{C}\right) \ln\left(\frac{C_j/C}{X_j/X}\right) \tag{6}$$

$$T = T_w + T_b = \sum_j \left(\frac{C_j}{C}\right) T_{wi} + T_b \tag{7}$$

$$E_w = \frac{T_w}{T} \tag{8}$$

$$E_b = \frac{T_b}{T} \tag{9}$$

where T indicates the Theil index of MAPE, T_w the intra-regional Theil index, T_b the inter-regional Theil index, C_i the efficiency of the i-th province, C the total efficiency of regions, C_j the total efficiency of the j-th region, X the number of regions, and E_w and E_b represent the contribution rates of inter- and intra-regional differences, respectively.

4. Data and Variables

4.1. Variable Selection

MAPE reflects the production capacity of sea areas. In terms of input indicators, combined with the existing research and considering data availability, the input indicators include the resource input, labor input, capital input, fish fry, and feed inputs. The collected or constructed data are as follows:

(1) Resource input: The "breeding sea area" in the China Fishery Statistical Yearbook is selected as the variable for resource inputs.

(2) Labor input: The "labor engaged in marine aquaculture" in the China Fishery Statistical Yearbook is selected as the variable for the labor input.

(3) Capital input: The "capital deposit of mariculture" is selected. Since these data are not clearly stated in the Statistical Yearbook, the "capital deposit of mariculture" is estimated using the perpetual inventory method, based on Fan et al. [65]. The formula is as follows:

$$K_{i,t+1} = I_{i,t+1} + (1 - \delta)K_{i,t} \tag{10}$$

The capital deposit of the base year is:

$$K_{it} = I_{it}/(g_{it} + \delta) \tag{11}$$

where $K_{i,t}$ represents the capital deposit of the i-th region in the t period, I the fixed investments, δ the depreciation rate, and g_{it} the geometric mean of the fixed assets.

(4) Output: The output indicators include both the desirable and undesirable outputs. To better measure the MAPE and eliminate the impact of the differences in the aquaculture structure on desirable output, in this study we take the mariculture production value as the desirable output indicator and use 2008 as the base year to deflate the mariculture production value from 2008 to 2019. Undesirable output mainly refers to pollutants discharged during mariculture. Based on Ji et al. [66], the output of nitrogen (N), phosphorus (P), and chemical oxygen demand (COD) equivalent pollutants from mariculture are selected as undesirable outputs in this study. The specific calculation formula is as follows:

$$E_{u,n} = \sum_{i,j} Y_{i,n} w_{i,j,n} e_{i,j,u,n} \tag{12}$$

$$w_{i,j,n} = \frac{\omega_{j,n} r_{i,j}}{\sum\limits_{j} \omega_{j,n} r_{i,j}} \tag{13}$$

$$C_n = E_{N,n} + \frac{E_{P,n}}{0.2} + \frac{E_{COD,n}}{20} \tag{14}$$

where $E_{u,n}$ represents the pollutant u (u = N, P, or COD) from mariculture production in the n area, $Y_{i,n}$ indicates the output of the i-th seafood in the n-th region, $w_{i,j,n}$ the proportion of the j-th breeding method used in the n-th region to produce the i-th seafood type, $e_{i,j,u,n}$ the pollution production coefficient of the n-th region using the j-th breeding method to produce the i-type seafood, $\omega_{j,n}$ the ratio of the j-th breeding method to the total output, C_n the equivalent pollutants in the n-th area, and $r_{i,j}$ represents whether the 0 or 1 variable can be used.

4.2. Study Area

China's east coast (18°10′–43°26′ N, 104°29′–125°46′ E) is located in eastern China, adjacent to the Bohai Sea in the north, the Yellow Sea and the East China Sea in the Middle East, the South China Sea in the south; facing Japan, North Korea, and South Korea across the sea in the north; Taiwan Province across the Taiwan Strait in the southeast; and Vietnam, Philippines, Brunei, and Malaysia across the sea in the south. In this study, we selected 10 coastal region as the sample: Liaoning Province, Hebei Province, Tianjin Municipality, Shandong Province, Jiangsu Province, Zhejiang Province, Fujian Province, Guangxi Zhuang Autonomous Region, Guangdong Province, and Hainan Province (Figure 1). Due to data availability and completeness, this study does not include Shanghai, Taiwan, Macau, and Hong Kong. As these areas have been engaged in mariculture for a long time, the 10 coastal region represent all the activities involved in China's mariculture production, and the study of the production efficiency of their sea areas can fully reflect the overall MAPE situation.

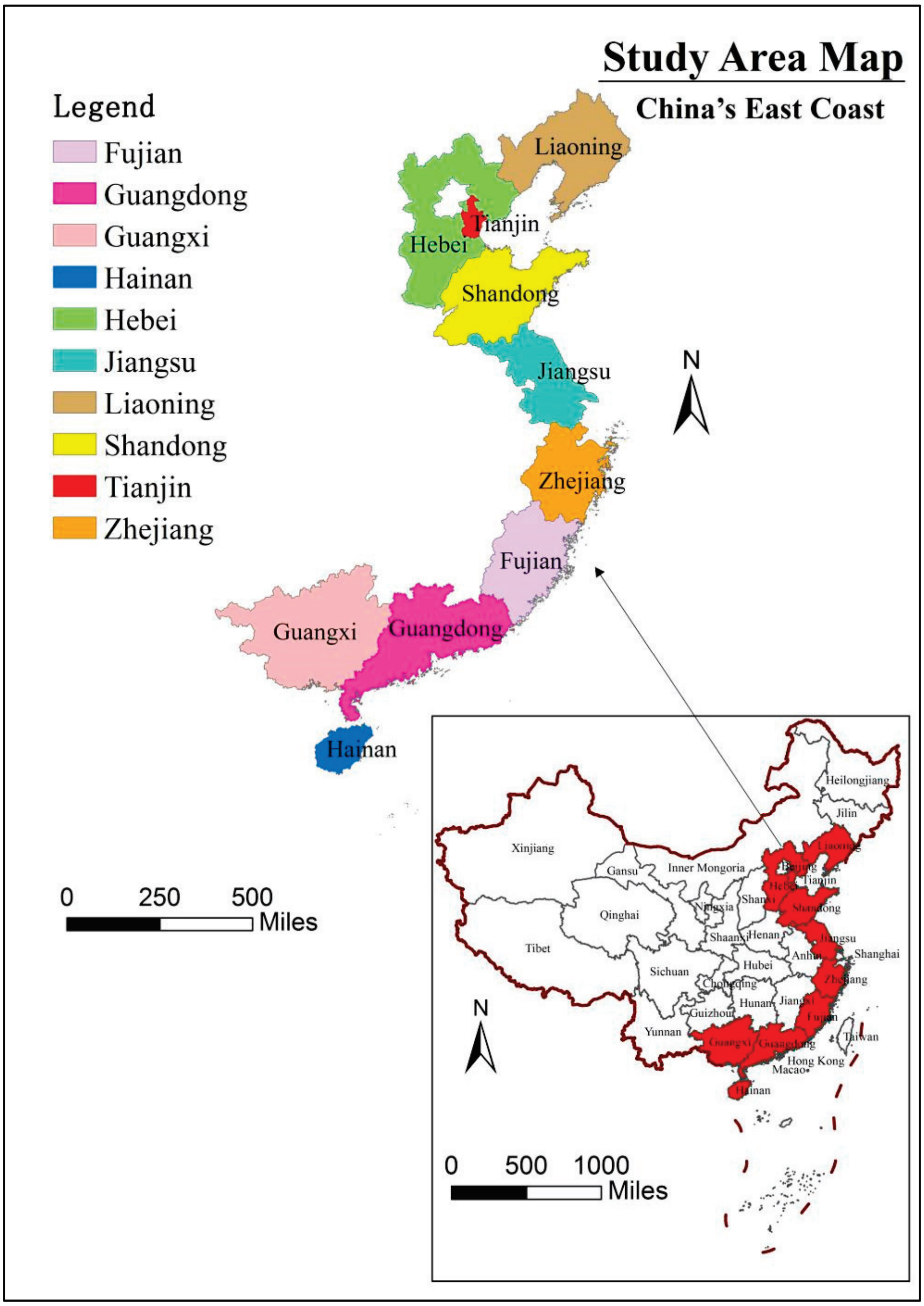

Figure 1. Study area map.

4.3. Data Sources

To ensure integrity and uniformity of the data, the related data for 2008–2019 were calculated to determine production efficiency. All relevant data are from the 2009–2020 China Fishery Statistical Yearbook. In order to remove the effects of price changes, we set 2008 as the base year and adjusted the mariculture production value to a constant price. The descriptive statistics of the variables are shown in Table 2. As shown in Table 2, there are large differences in the input–output indicators of the 10 coastal regions.

Table 2. Descriptive statistics.

Statistics	Desirable Output	Undesirable Output	Input		
	Mariculture Production Value (100 Million CNY)	Equivalent Pollutants (Tons)	Mariculture Area (Hectare)	Capital Deposit of Mariculture (100 Million CNY)	Mariculture Labor (10 Thousand People)
Maximum	6719.58	34,387.98	942 05	1228.59	225,139.00
Minimum	23.82	37.89	813.00	5.32	621.00
Mean	1886.96	4877.85	208,518.81	243.55	88,599.88
Median	1297.42	2073.36	134,103.00	128.05	61,106.00
Standard deviation	1671.88	6785.38	234,478.53	301.28	66,168.46

5. Results

5.1. Statistic Analysis of MAPE

5.1.1. Temporal Disparity Analysis of MAPE

Using MaxDEA7 software, MAPE can be calculated using the S-EBM mode. See Table 3 for details. The efficiency is divided into four grades [67]: the low-efficiency area (efficiency within (0, 0.7)), lower-efficiency area (efficiency within (0.7, 0.8)), medium-efficiency area (efficiency within (0.8, 1)), and high-efficiency area (efficiency greater than or equal to 1). From Table 3, the spatiotemporal differences in the MAPE vary greatly, and a specific analysis is presented below.

Table 3. Mariculture areas' production efficiency.

Province	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Liaoning	0.706	0.788	0.801	0.642	0.849	0.536	0.615	0.523	0.47	0.424	0.387	0.542
Hebei	0.566	0.588	0.794	0.634	0.638	0.579	0.619	0.609	0.588	0.522	0.53	0.773
Tianjin	1.081	1.212	1.134	0.925	1.055	1.2	1.157	1.166	1.2	1.136	1.123	1.1
Shandong	0.867	1.017	1.044	1.118	1.097	0.921	1.006	0.924	0.806	0.823	0.707	1.02
Jiangsu	1.224	1.229	1.127	1.328	1.278	1.315	1.26	1.29	1.319	1.295	1.313	1.243
Zhejiang	0.71	0.751	0.882	0.927	1.052	1.032	1.034	1.045	0.913	1.119	1.058	1.076
Fujian	1.023	0.888	0.89	0.853	0.923	0.88	0.843	0.856	0.88	1.051	1.009	1.008
Guangdong	1.136	1.131	1.086	1.084	1.092	1.02	1.013	1.014	1.015	1.072	1.072	1.082
Guangxi	1.09	1.083	1.077	0.557	0.71	0.502	0.861	0.85	1.053	1.001	1.036	1.043
Hainan	1.072	1.088	1.103	1.136	1.131	1.146	1.162	1.18	1.203	1.104	1.138	1.129
Average	0.947	0.977	0.994	0.920	0.982	0.913	0.957	0.945	0.944	0.954	0.937	1.001

According to the average value of MAPE from 2008 to 2019 (Table 3), the overall MAPE fluctuates and increases. The overall level of MAPE is relatively high, namely, in the medium–high-efficiency areas. In 2008, the efficiency was 0.947 and then increased continuously. From 2010 to 2013, efficiency was in a state of falling volatility, and then from 2014 to 2019, the average efficiency recovered and entered the high-efficiency area in 2019. Overall, the MAPE has generally shifted from a medium-efficiency area to a high-efficiency one. The reason for this is that the early stage of the study was at the beginning of the country's advocacy of marine construction and marine development. As such, with the development of mariculture in various regions, the scale of mariculture continued to expand, and the maricultural area and capital investment increased rapidly, which promoted the MAPE. However, with the expansion of the scale, there are still problems such as extensive mariculture methods, more undesirable output, and serious pollution of sea areas, resulting in MAPE staying in the middle-efficiency stage. Therefore, the pollution treatment capacity of undesirable outputs has not been fully utilized, thereby presenting a lower mariculture efficiency [16,25]. In the latter part of the study period, China advocated building an environmentally friendly society and paid more attention to the treatment of undesirable outputs during the breeding process, which resulted in increased efficiency.

5.1.2. Spatial Disparity Analysis of MAPE

As shown in Table 3, the MAPE changed significantly from 2008 to 2019. In 2008, among the 10 regions, Tianjin, Jiangsu, Guangdong, Fujian, and Hainan were highly efficient, whereas the other regions were in the low- or medium-efficiency areas. The overall efficiency level was medium and the spatial pattern was characterized by high efficiency in the south and central regions and low efficiency in the north regions. In 2013, the number of regions that reached effective efficiency decreased to five compared with the beginning of the study, whereas the efficiencies of Guangxi and Fujian provinces were low. The overall pattern reflects low efficiency in the north and south and high efficiency in the central regions. In 2019, the overall MAPE improved greatly and the regional differences narrowed. Among them, Liaoning and Hebei showed a low efficiency, whereas the other regions showed efficiencies above 1, which achieves an efficient MAPE state. The overall spatial pattern shows a highly efficient state in the south and a low one in the north.

As shown the box chart of MAPE from 2008 to 2019 (Figure 2), the variance in the MAPE was very different for each province. Among these, the variances of Liaoning, Guangxi, Shandong, and Zhejiang were large, indicating that the MAPE in these regions was unstable over the 12 analyzed years and the gap between the years was significant. Guangdong, Hainan, and Jiangsu showed relatively small variances, indicating stable MAPE, and the MAPE in these regions was always at a high level, as can be seen in the box chart. Regions with relatively stable production efficiencies should maintain a good development level. Conversely, more attention should be paid to the proportion of the production input in mariculture areas and appropriate adjustments should be made.

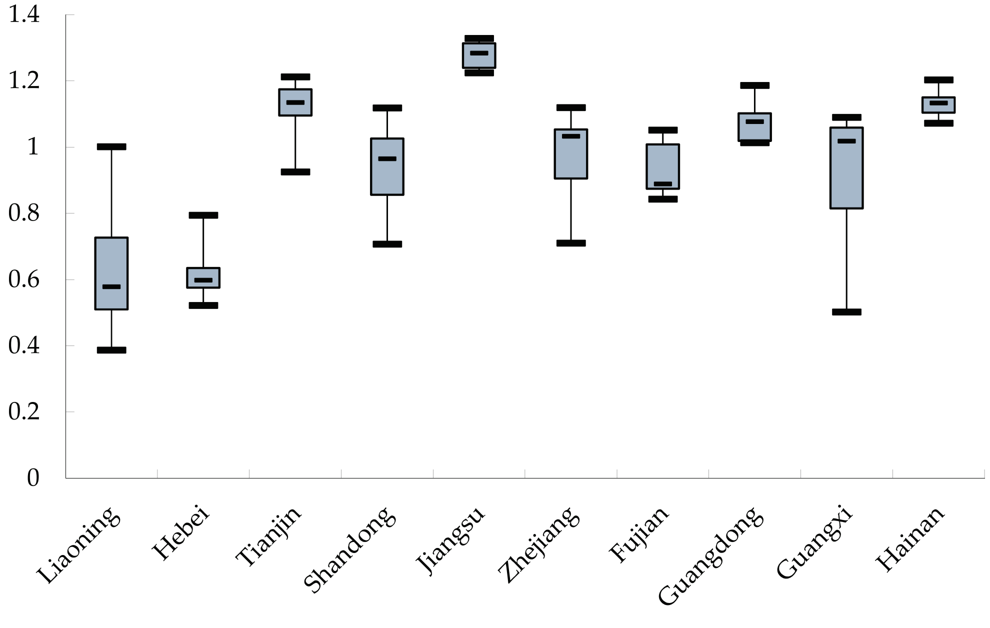

Figure 2. Box chart of MAPE during 2008–2019.

5.1.3. Inter-Provincial Evolution Type Analysis of MAPE

Based on the above analysis, the temporal and spatial differences in MAPE vary greatly. Referring to Sun et al. [68] and the degree of efficiency fluctuations of regions, in this study we divided the 10 coastal regions into high-efficiency stable, medium-efficiency fluctuating, and low-efficiency fluctuating types. For the high-efficiency stable type, the average MAPE is greater than 1; for the medium-efficiency fluctuating type, it fluctuates between 0.9 and 1; and for the low-efficiency fluctuating type, it is below 0.9. Therefore, the evolution characteristics of the efficiency of each province can be obtained (Figure 3).

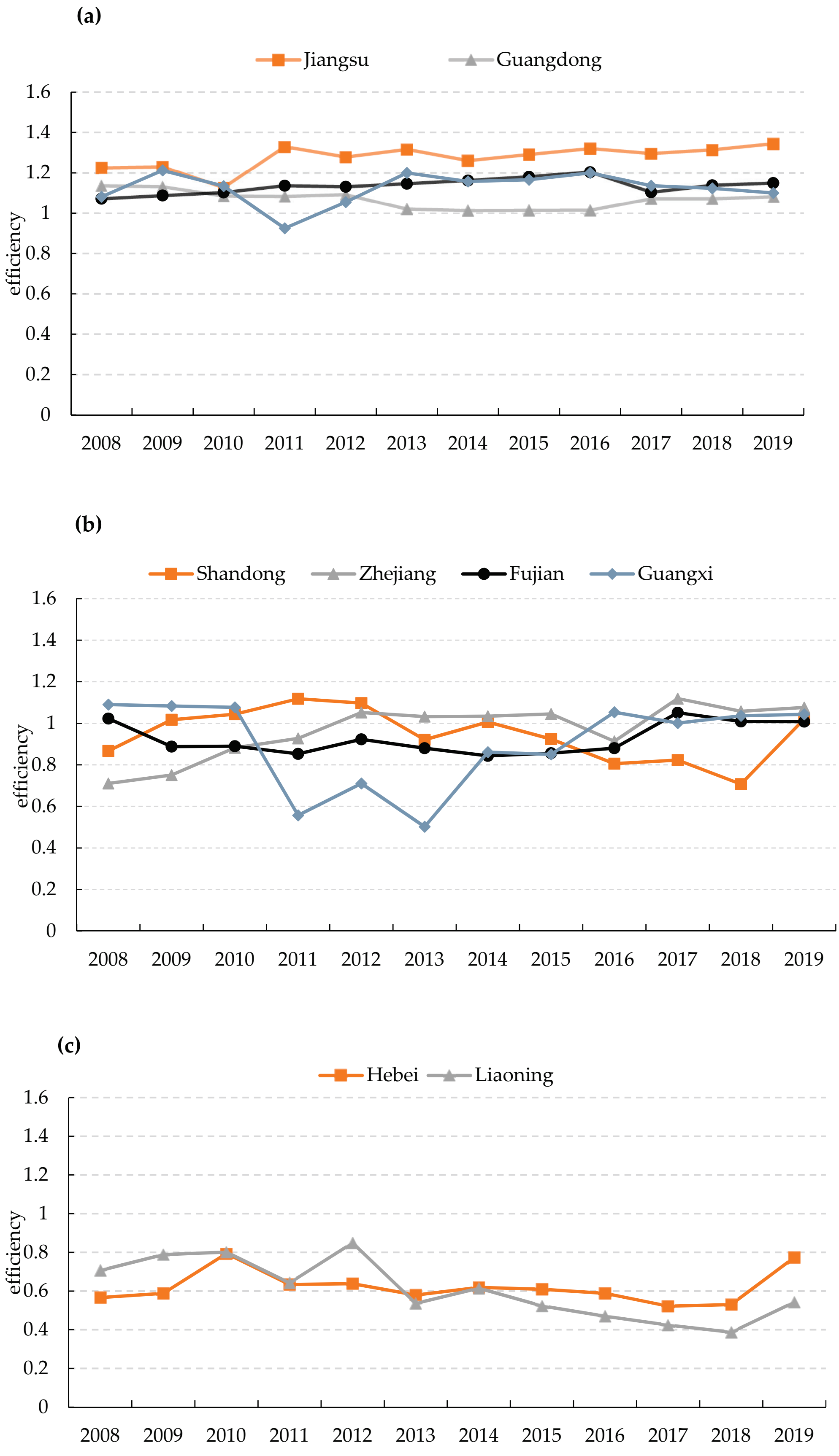

Figure 3. Evolution types of mariculture areas' production efficiency; (**a**). High-efficiency stable type; (**b**) Medium-efficiency fluctuating type; (**c**) Low-efficiency fluctuating type.

The high-efficiency stable type includes Jiangsu, Guangdong, Tianjin, and Hainan provinces (Figure 3a). Among these, the mariculture industry in Guangdong, and Jiangsu is relatively developed, the structure of their mariculture is reasonable, the scale of mariculture areas is large, and the development of mariculture is emphasized. Additionally, these four provinces are all located in the core areas of the coastal economic areas, thus being able to attract talent and create supporting facilities for mariculture. These provinces also have high levels of scientific and technological development, and the treatment of environmental pollution is more scientific, which leads to a higher production efficiency of mariculture. The main reason for the high production efficiency in Tianjin is that the exploitation of the ocean is relatively weak, and the scale of the mariculture area is relatively small, which results in less sea area pollution. Hainan has a vast sea area and abundant sea resources, and the good marine environment leads to the province requiring less input and producing more value output. Additionally, the province attaches great importance to the treatment of pollution.

The medium-efficiency fluctuating type includes Shandong, Zhejiang, Fujian, and Guangxi (Figure 3b). The MAPE of Shandong and Zhejiang was relatively low at the beginning of the study period, and the production efficiency fluctuated and increased since then, indicating that the productivity of the mariculture areas of these regions has great potential. Shandong, Fujian, and Zhejiang belong to the areas with the early development of mariculture, strong output strength, a rapidly developed economy, and a high level of scientific and technological development. However, due to the large scale of mariculture, there are more undesired outputs brought about by mariculture, which led to low efficiency in the early stage of the research. Since the implementation of the Twelfth Five-Year Guidelines of China, these areas have actively responded to the call of national policies, strengthening the construction and investment in mariculture areas, and strengthening the treatment of environmental pollution, which have greatly improved the MAPE. With the local government's management and control of the production environment of the mariculture area, the efficiency has been improved. The main reason for the medium production efficiency in Guangxi is that economic development is relatively backward, but the local government has attached significant importance to the development of mariculture, increased inputs in mariculture, and has guaranteed sufficient financial, labor, and material resources to the development of mariculture.

The low-efficiency fluctuating type includes Hebei and Liaoning provinces (Figure 3c). In Hebei and Liaoning provinces, the foundation of mariculture is relatively poor, the method of mariculture is extensive, and the structure is unreasonable. Moreover, Hebei has a low-level economy, science, and technology, and the unreasonable treatment of undesirable outputs has resulted in a low MAPE. As the scale of mariculture expanded, the pollution caused by mariculture in Liaoning intensified. The production efficiency showed slow growth due to the pursuit of large-scale production and the neglect of undesirable outputs. Subsequently, the MAPE continued to increase in recent years based on technological innovation, policy preferences, economic advantages, and increased investment in mariculture. Sun and Ji [69] also reached a similar conclusion when they found that the factor input bias of technological progress is not satisfactory, and technological innovation and reduced dependence on resources and environment can improve the factor allocation of the mariculture industry.

5.2. Dynamic Analysis of MAPE

5.2.1. The GML and Decomposition Indexes

By calculating Formula (3), the GML trend of China's mariculture areas and its decomposition index from 2008 to 2019 can be drawn (Figure 4). Based on this analysis, the GML of mariculture areas is in a state of fluctuation. The GML increased from 1.035 in 2008–2009 to 1.574 in 2011–2012, and then decreased to 0.950 in 2014–2015. Over the next four years, GML has been fluctuating. During the 12 years from 2008 to 2019, the average GML was 1.039, indicating that the production efficiency was slowly increasing. Regarding the GMLTC, from 2008 to 2019, the average change index was 1.021, indicating that the technical progress showed a fluctuating rising trend. At the same time, the change trend of the GMLTC is generally consistent with the change trend in GML, indicating that technical progress has a significant driving effect on the production efficiency. Yu et al. [27] also reached a similar conclusion when they found that the mariculture efficiency in China increased by 6.45% from 2004 to 2016, and technological progress was the main driving force for this. For the GMLEC, from 2008 to 2019, it increased from 1.038 to 1.125, and the change trend was reversed with the GML. Based on the above analysis, China attaches great importance to technological inputs and innovations in mariculture areas and constantly promotes technical progress, thus leading to an increase in the promotion of production efficiency.

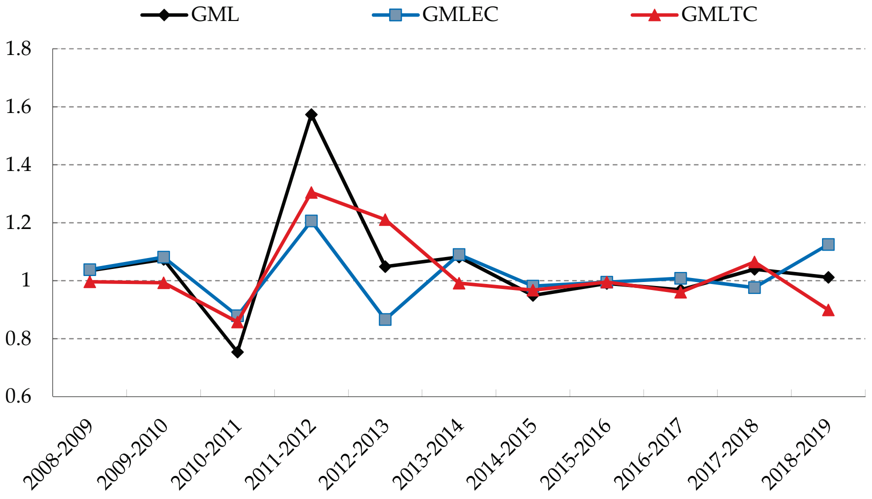

Figure 4. Temporal difference of GML and its decomposition indexes.

5.2.2. Spatiotemporal Characteristics of the GML and Decomposition Indexes

By decomposing the GML, in this study we obtained the GML and its decomposition for each province (Table 4). The GML values of nine regions were greater than one, indicating that the production efficiency was generally on the rise from 2008 to 2019 in various regions, except for Liaoning province. For the GMLEC, the efficiency indexes of Guangdong and Liaoning provinces were below one, and others were above one, showing a pattern of high technical efficiency in the center and south and of low technical efficiency in the north. All 10 regions had technical progress indexes above one, and the differences among them were small. Based on the analysis, Shandong, Liaoning, Hebei, Fujian, Guangdong, and Hainan were mainly technology-driven provinces, whereas the others showed a combination of technological progress and technological efficiency. In general, eight of the 10 mariculture areas had three indexes higher than one, and the increase in GML was mainly due to the efficiency of technical progress.

Table 4. Spatial differences in the GML and decomposition indexes.

Province	GML	GMLEC	GMLTC
Liaoning	0.985	0.974	1.011
Hebei	1.053	1.020	1.032
Tianjin	1.065	1.019	1.045
Shandong	1.023	1.002	1.021
Jiangsu	1.005	1.003	1.002
Zhejiang	1.072	1.050	1.021
Fujian	1.015	1.000	1.015
Guangdong	1.022	0.999	1.023
Guangxi	1.113	1.100	1.012
Hainan	1.032	1.005	1.027

Four time sections were selected from 2008 to 2009, 2012 to 2013, 2015 to 2016, and 2018 to 2019 to analyze the spatiotemporal characteristics of the GML and its decomposition indexes from 2008 to 2019, considering undesirable outputs.

(1) The GML index (Figure 5): From 2008 to 2009, the GML values of Tianjin, Shandong, Liaoning, Hebei, and Zhejiang were greater than 1, indicating that the production efficiency of these regions increased. In other regions, the GML was less than one and the production efficiency showed a downward trend. In terms of space and geography, production efficiency showed an upward trend in the north and central region and a downward trend in the south. From 2012 to 2013, the GML values of Hainan, Guangxi, Hebei, and Zhejiang were less than one, indicating that the production efficiency showed a downward trend. From 2015 to 2016, all values, except for the production efficiency in Liaoning, Shandong and Zhejiang, showed a downward trend, whereas the other regions showed an upward trend, with slight increases. From 2018 to 2019, the production efficiency in Jiangsu, Shandong, Guangdong, Fujian, and Zhejiang showed a downward trend, whereas the rest showed a slight increase; in general, the north and south regions showed an upward trend.

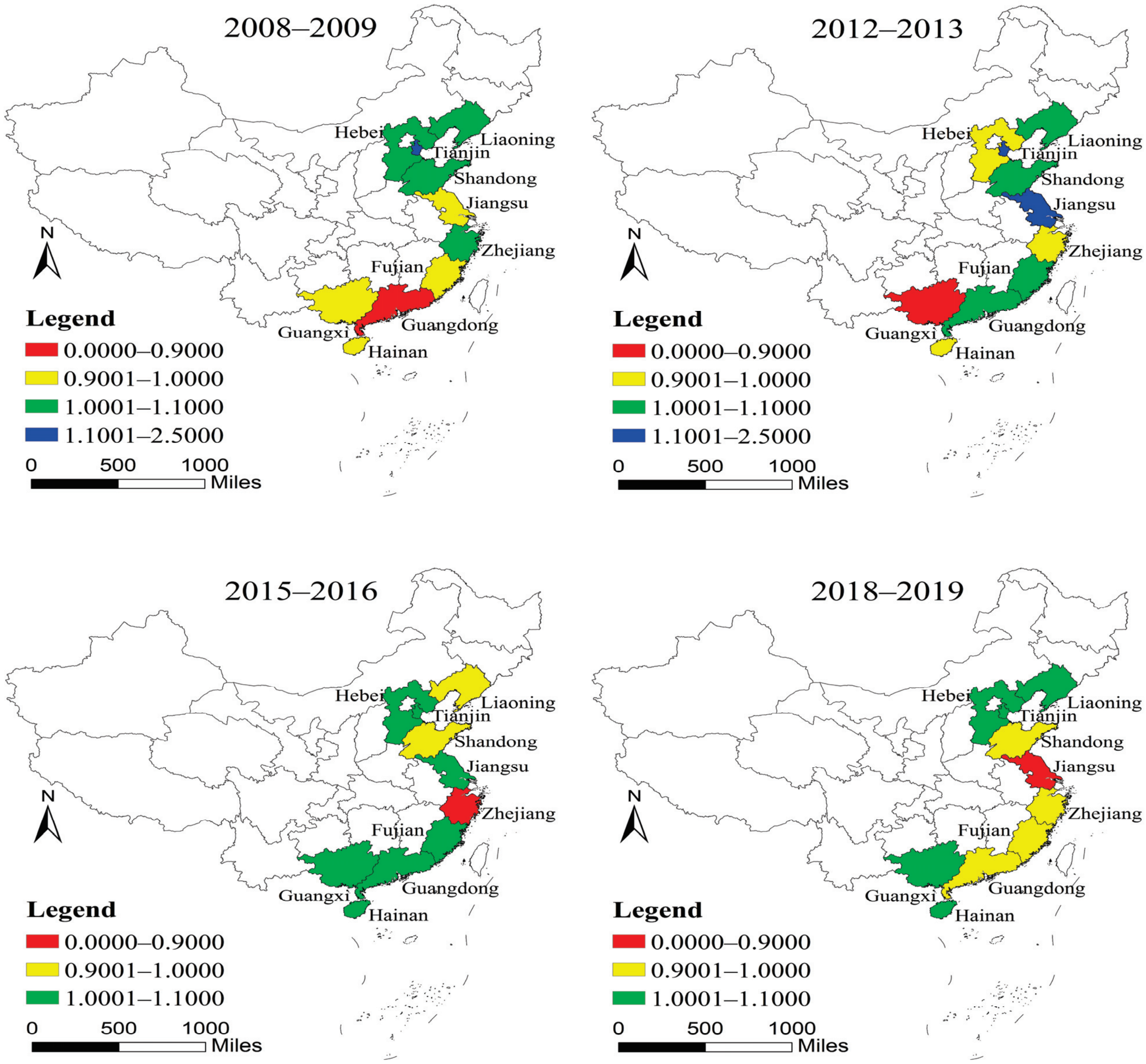

Figure 5. Spatial changes in GML of production efficiency.

(2) The GMLTC index (Figure 6): From 2008 to 2009, the change index of GMLTC in Tianjin, Hebei, and Fujian was greater than one, showing an upward trend. The other regions showed different degrees of decline. Namely, the spatial pattern of the technological progress showed an upward trend in the central and north region and a downward trend in the south. There was a major change from 2012 to 2013, with the exception of Hainan and Zhejiang, which showed a slow downward trend, whereas the other regions experienced a sharp increase. In terms of space and geography, there was a downward trend in the south and central region and an upward trend in the north. Except for Guangxi, Tianjin, Fujian, and Zhejiang, the GMLTC of which remained less than one from 2015 to 2016, all other regions showed an upward trend, and the increase was relatively small. During 2018–2019, the GMLTC index of Liaoning, Hebei, Shandong, and Jiangsu decreased significantly, and only the indexes of Guangxi, Hainan, and Tianjin were greater than one, indicating that the technological progress of these three regions had increased. On the whole, the GMLTC index showed a trend of increasing first and then decreasing, and the changes in the south and north regions were more obvious, and the changes in the middle were smaller.

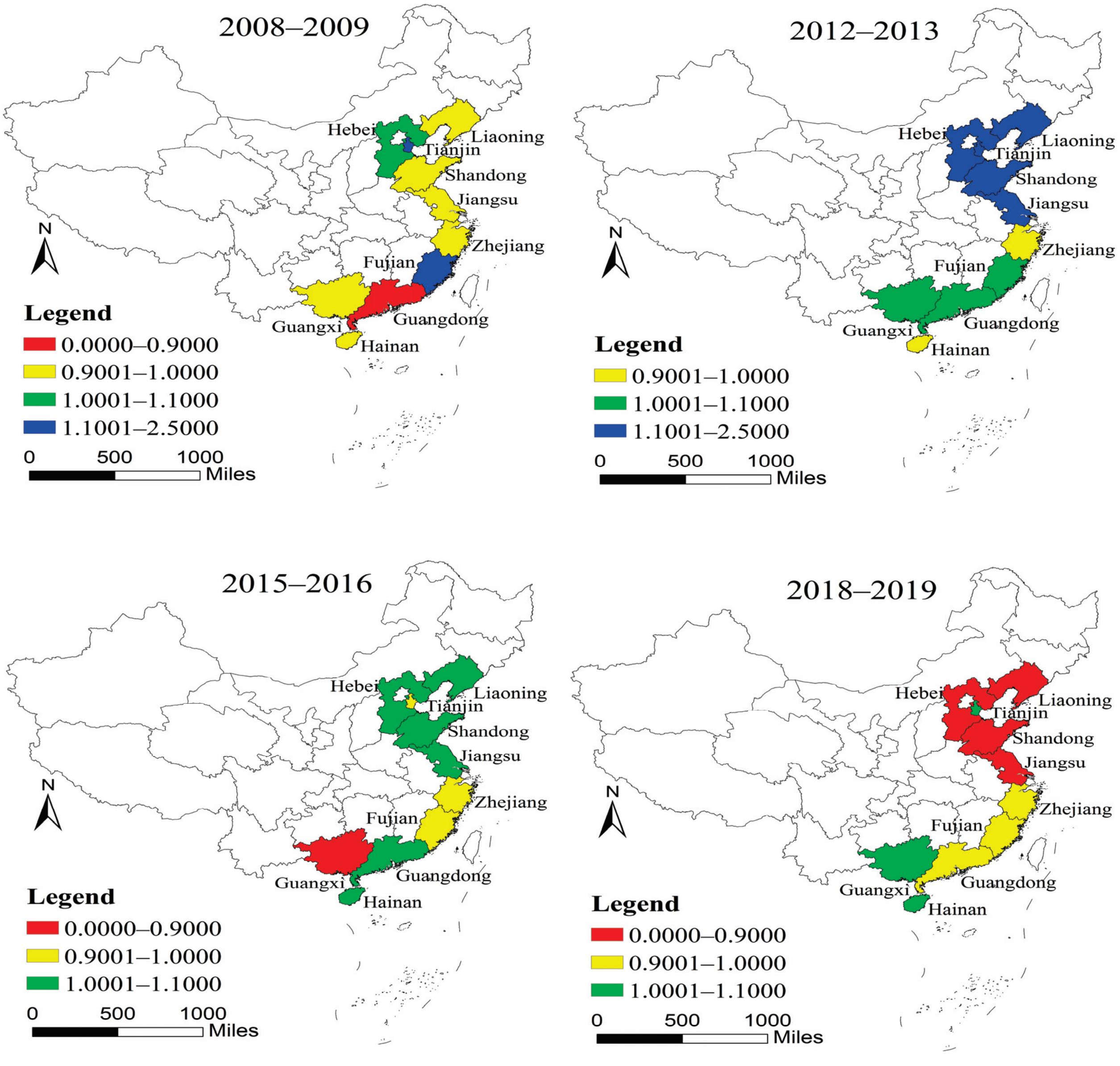

Figure 6. Spatial changes in GMLTC.

(3) GMLEC index (Figure 7): From 2008 to 2009, in addition to Guangxi, Guangdong, and Fujian, the GMLEC index of other regions was greater than one, indicating that technical efficiency showed an upward trend. The indexes of Hebei, Jiangsu, Zhejiang, and Hainan were close to one, indicating that there was no significant change in technical efficiency during the research phase. From 2012 to 2013, Liaoning, Hebei, Shandong, and Guangxi showed a significant downward trend, whereas the other regions showed little change. From 2015 to 2016, only the GMLEC of Liaoning, Shandong, Hebei, and Zhejaing showed a downward trend, whereas the indexes of other regions showed an upward trend. From 2018 to 2019, Liaoning, Hebei, and Shandong showed a significant upward trend, whereas Tianjin, Jiangsu, Fujian, and Hainan showed a slow downward trend. Overall, technical efficiency showed a trend of first decreasing and then increasing, and the change in the technical efficiency index in the northern region was more obvious.

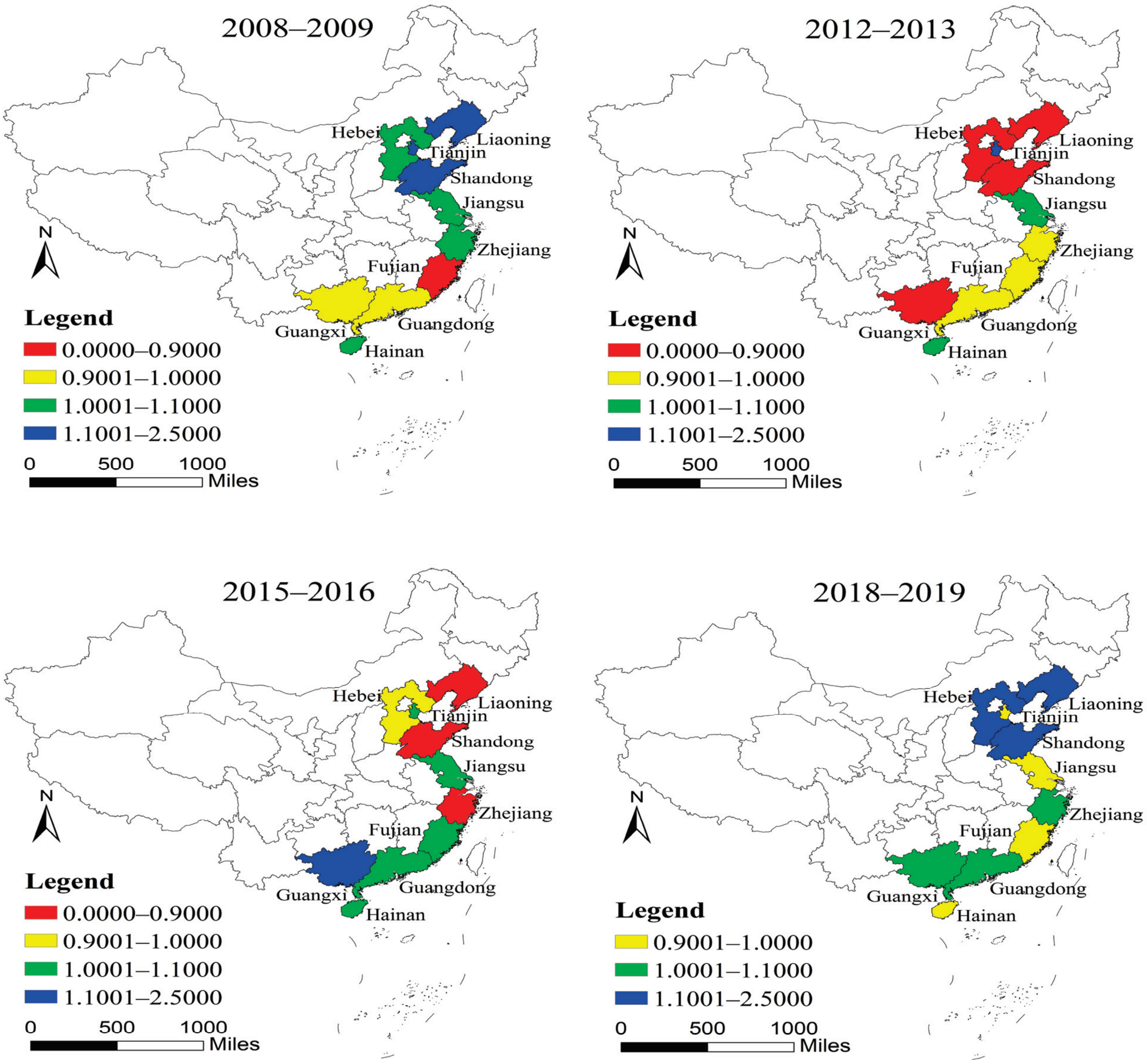

Figure 7. Spatial changes in GMLEC.

5.3. Spatial Difference Decomposition of MAPE

Based on the above analysis, there were significant spatiotemporal disparities in terms of MAPE in China's east coast from both static and dynamic perspectives. To explore the structure and causes of the differences in production efficiency among regions, in this study we used the Theil index to decompose the differences in MAPE [70], as per Figure 8.

Overall, the MAPE in the coastal regions differed significantly from 2008 to 2019, and the Theil index fell rapidly from 0.026 in 2008 and 0.023 in 2009 to 0.009 in 2010, and the difference between regions reached the lowest value. Since then, it tortuously increased to 0.005 in 2018. The overall trend is represented by a decline, followed by an increase, and then a decrease, indicating that the differences in MAPE first decreased and then increased, and finally decreased. To further explore the causes of the differences and to narrow them in MAPE, in this study we analyzes these structural differences and condense the 10 regions into three regions based on existing research [71]. Among them, the circum-Bohai Sea region includes the Liaoning, Hebei, Tianjin, and Shandong provinces; the Yangtze River Delta region includes the Jiangsu, Zhejiang, and Fujian provinces; and the Pearl River Delta region includes the Guangdong, Guangxi, and Hainan provinces.

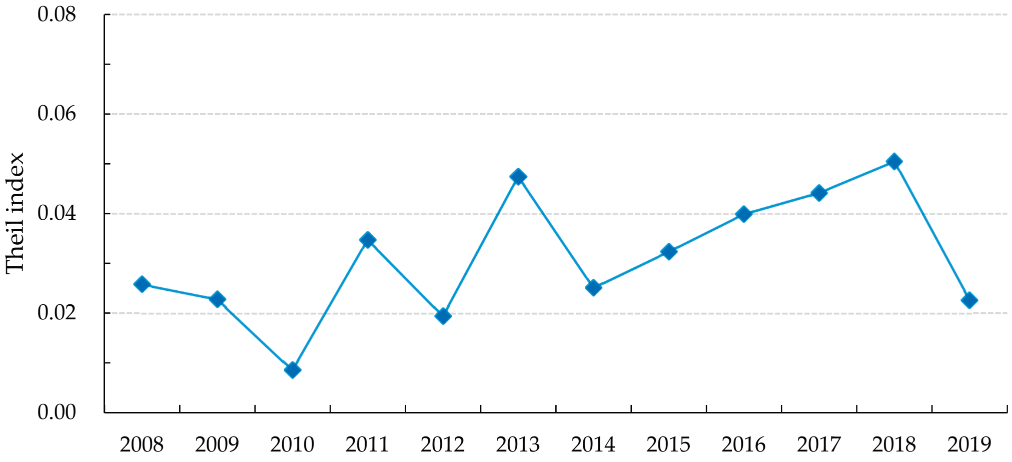

Figure 8. Theil indexes of MAPE from 2008 to 2019.

By calculating Formulas (8) and (9), the decomposition results of the Theil index for the regional groups can be obtained (Table 5). From 2008 to 2019, the relationship between the intra- and inter-regional difference contribution rates of MAPE changed significantly. The intra-regional difference contribution rate increased from 66.37% to 87.67% and then decreased to 64.06%, whereas the inter-regional difference contribution rate decreased from 33.63% to 12.33% and then increased to 35.92%, which means that the role of the intra-regional differential contribution rate first strengthened and then weakened, and the inter-regional difference contribution rate first weakened and then strengthened. From 2009 to 2014, the contribution rate of intra-regional differences exceeded 80.00%, indicating that intra-regional differences occupied an absolute dominant position in the overall differences. Although it was still dominated by intra-regional differences, the situation changed significantly in 2018, with the contribution rate falling to 50.59%. Then, in 2019, the contribution rate of intra-regional differences increased. Overall, intra-regional differences were always the dominant factor for MAPE differences. This is similar to the results of agricultural studies. Pang et al. [72] examined the regional differences and spatiotemporal patterns of the carbon emission intensity of agriculture production, and the results showed that the overall differences were caused by intra-regional differences.

At the same time, the main factors causing intra-regional differences also changed. The intra-regional differences in the circum-Bohai Sea region showed an upward trend, whereas the Pearl River Delta region was in a relatively stable state of development but showing a downward trend, with the greatest degree of decline being from 28.73% at the beginning of the study period to 11.74% at the end of the study period. In general, from 2008 to 2019, the intra-regional differences in the circum-Bohai Sea region were the main reason for the overall intra-regional differences, whereas the Yangtze River Delta was the secondary factor. However in 2011, the intra-regional differences in the Yangtze River Delta region became the main factor influencing the overall intra-regional differences, followed by the circum-Bohai Sea region and the Pearl River Delta region. Analyzing the Theil index of MAPE, we note that intra-regional differences are the main factor causing the differences in MAPE, but the contribution of the inter-regional differences to the overall difference is increasing.

Table 5. Contribution rate of the Theil index decomposition from 2008 to 2019.

Year	Intra-Region (%)			Sum of Intra-Region (%)	Inter-Region (%)
	Circum-Bohai Sea Region	Yangtze River Delta Region	Pearl River Delta Region		
2008	37.24%	28.73%	0.40%	66.37%	33.63%
2009	56.09%	27.79%	0.28%	84.17%	15.83%
2010	36.45%	42.36%	3.24%	82.05%	17.95%
2011	30.83%	19.05%	37.79%	87.67%	12.33%
2012	40.11%	15.45%	30.61%	86.17%	13.83%
2013	41.16%	10.33%	33.10%	84.60%	15.40%
2014	55.82%	17.38%	9.37%	82.56%	17.44%
2015	52.97%	14.54%	8.81%	76.32%	23.68%
2016	51.67%	14.74%	2.37%	68.78%	31.22%
2017	49.95%	3.22%	0.63%	53.79%	46.21%
2018	45.17%	4.89%	0.52%	50.59%	49.41%
2019	51.19%	11.74%	1.15%	64.08%	35.92%

6. Conclusions and Discussion

6.1. Main Conclusions and Policy Implications

This study analyzed the spatiotemporal disparities of MAPE from both static and dynamic perspectives. Using the S-EBM model and considering undesirable outputs, the MAPE of 10 coastal regions in China as the measurement object was measured and analyzed statically from 2008 to 2019. The GML index was further used to dynamically depict the production efficiency, and the Theil index was used to analyze the main reasons for the spatial differences in MAPE. The main conclusions are as follows.

Based on the static analysis, the MAPE showed fluctuations and increased from 2008 to 2019, and the overall level of MAPE was relatively high, namely, in the medium-high efficiency area. The efficiency of each province differed greatly and the overall spatial pattern was high in the center and south and low in the north. Based on the analysis of the spatiotemporal differentiation, the efficiency evolution can be divided into three types: high-efficiency stable, medium-efficiency fluctuating, and low-efficiency fluctuating.

Based on the dynamic analysis, regarding the GML and GMLTC, the production efficiency and technical progress showed a fluctuating rising trend, and technical progress had a significant driving effect on the production efficiency. The GML of production efficiency in the north and south region showed an upward trend, the GMLTC in the south and north regions were more obvious, and the changes in the middle were smaller, and the GMLEC in the northern region was more obvious.

Based on the Theil index and its contribution rate, the differences in MAPE first decreased and then increased, and finally decreased. The role of the intra-regional differential contribution rate first strengthened and then weakened, and the inter-regional first weakened and then strengthened. Intra-regional differences were the main factors that caused the differences in MAPE and the intra-regional differences in the circum-Bohai Sea region were the main reason for the overall intra-regional differences.

Based on these results, there are several policy implications for improving the MAPE in China. First, attention should be paid to the balanced development of each region, and regions with low production efficiency should further increase scientific and technological investment in mariculture, and seek more reasonable mariculture methods; second, the government should establish a monitoring center for the pollution of mariculture areas to strengthen supervision and guidance; furthermore, policies for exchange and cooperation among different mariculture areas need to be introduced to promote information sharing and technical exchange, to narrow regional differences in MAPE, and to achieve sustainable development.

6.2. Limitations and Discussions

These empirical results are of great significance for understanding how to strengthen the sustainable development and utilization of mariculture areas from the perspective of production efficiency. Reducing undesirable output and narrowing regional differences are the preferred strategies to improve the MAPE. This can be reflected indirectly through measurement of the input-output indicators of MAPE and the further analysis of the spatiotemporal disparities. Beyond that, there should be some limitations and discussion about our proposed models and findings that provide useful directions for the future research. A limitation of this study was that it ignored more possible relevant factors other than the region, such as mariculture structure and mariculture mode. The regression analysis with the efficiency score as the dependent variable should comprehensively consider the impact of other influencing factors on the MAPE. In addition, an environmental control group should be added, and the expected and unexpected data should be compared and analyzed in future research. Furthermore, in our study we took 10 coastal regions as samples, with a small number and a relatively broad range. We are considering extending the sample to coastal prefecture-level cities in the future, and the research results may be more representative. Of course, if the data are available, coastal regions of other countries will also be an object of our study. Such research is more intuitive and interesting and can provide help for the sustainable development of mariculture areas.

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Abbreviations

COD	Chemical oxygen demand
DEA	Data envelope analysis
DMU	Decision-making unit
EBM	Engel–Blackwell–Miniard
GML	Global Malmquist–Luenberger
GMLEC	Global Malmquist–Luenberger technical efficiency
GMLTC	Global Malmquist–Luenberger technical progress
LCA	Life cycle assessment
MAPE	Mariculture area production efficiency
N	Nitrogen
P	Phosphorus
SBM	Slacks-based measure
S-EBM	Super-efficiency Engel–Blackwell–Miniard
SFA	Stochastic frontier analysis
TFP	Total factor productivity
TTP	Tornqvists–Theil

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Coevolution of Economic and Industrial Linkages within the Land-Sea Industrial Structure of China

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Abstract: The joint development of continental and marine economies has become an important driving force for the upgrading of industrial structures. However, because of the differences in resource endowment and development potential, developing industrial structures and the quality of economic development are uneven among regions. In this study, the added values of three land-sea industries in the three marine economic circles of northern, eastern, and southern China, were employed to clarify the evolutionary behavior of the industrial structure of these three circles on the land and sea; the synchronization, lag, equilibrium, and dislocation of developing the industrial structure were also explored which a gray relational model based on convex judgment and gray time difference analyses were used to construct a relational model from the static and dynamic aspects of the system, and the internal and external linkages of the industrial structure of the three circles were analyzed from the perspective of industrial correlation. The results show that: (1) Correlations among the linkages of the three economic circles in the marine industrial structure, both including and without temporal and spatial differences, and the marine feedback driver, differ markedly. (2) The effects of feedback for marine industrial development from the Eastern Marine Economic Circle were stronger, whereas those of the Southern Marine Economic Circle were weak and those of the Northern Marine Economic Circle were ambiguous. (3) A significant difference was observed in the degree of coevolution among the land-sea industrial structures of these areas. The Northern Marine Economic Circle exhibited a slightly higher degree of coevolution than the other two economic circles, showing a stable trend of coevolution and wide spatial development. The eastern and southern circles displayed high degrees of coordination in developing their industrial structures. The research results provide a reference for regional adjustment and optimization of industrial structure.

Keywords: land-sea industrial structure; convex gray correlation model; economic coevolution; coordinate economic development

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1. Introduction

The 21st century has been called the "century of the marine economy", which was stated in the "United Nations Convention on the Law of the Sea", published in May 2001. The sea is both a cradle of life and a source of resources, as it contains abundant strategic resources critical to human development, such as energy, minerals, water, and rare metal resources [1]. Explosive population growth, the overexploitation of land resources, and environmental degradation have pressured lands to facilitate the development of human societies [2]. The marine environment provides a second space from which resources may be acquired for socioeconomic development [3]. Most of the marine developing countries are facing the problem of insufficient energy; thus, they must plan for the research and development of marine renewable energy resources [4]. Coastal communities worldwide attach great importance to developing the marine economy. Under the guidance of the marine power theory, the United States was transformed from a naval power into a marine power. An old maritime empire, the United Kingdom, continued to focus on marine development and enjoyed the dividends of using marine resources. Japan became a maritime nation in the early 1990s. According to the "Bulletin of Marine Economic Statistics of China 2020" [5], despite the impact of COVID-19, China's gross operating profit was USD 1.1596 trillion in 2020, contributing 7.34% of the total gross domestic product (GDP), which is twice the contribution of China's marine GDP in 2000.

The rapidly developing marine economy is inseparable from the land, which serves as a firm foundation for overall socio-economic development. Land-sea economics is a subsystem within the economic development system, which forms a complex network through the bidirectional flow of resources, mutual energy flows and environmental influences, and complementary rights and interests between terrestrial and marine resources [6]. The interactions between continental and marine industries are important linkages for promoting the coordinated development of terrestrial and marine environments. The exploitation of marine resources and the sustainable development of marine industries depend on existing land economies and technologies, while the processing of marine products and constructing infrastructure must also be conducted on land, especially in coastal zones. This transfers marine development from the sea to the land, and promotes the mutual development of land-sea economies via industrial linkages. Specific industrial structures serve as the corresponding levels of economic development. Continental and marine industries are interconnected, and the evolution of their industrial structures also influences one another. If the development of land-sea industries is separated, a lack of rational planning and a clear understanding of the linkages among the industrial structures of these economies and their development will be greatly hindered.

Marine resources play a key supporting role in developing land-sea economies [7,8]. Based on the continuous and dynamic preservation, protection, and development of natural resources, coastal zone management should encourage cooperation and exchange between local governments and federal agencies to ensure the reasonable and coordinated economic growth of land-sea industries [9,10]. However, because of the high uncertainties regarding marine and coastal species (e.g., endemism, diversity, and population sizes), contradictions between sustainable development and social and socioeconomic priorities, and the ambiguity of developmental positions, rights, and interests, different countries (and regions within them) encounter bottlenecks in resource management and coordinated industrial development [11–14].

By considering the land and marine systems independently; comprehensively combining their industrial outputs and the structures of their economic systems; and considering the connection of information flow and logistics as the link between them, land-sea industrial development may be scientifically planned to promote the construction of complementary systems for utilizing terrestrial and marine resources [15]. Structural correspondences, complementary relationships, and spatiotemporal co-occurrences exist between continental and marine industrial systems, as well as competition among marine industrial systems [16]. Therefore, extending the network; coordinating the extension; repairing, strengthening, and enhancing coordination between land-sea industrial chains are effective means of promoting the coordinated development of the land and sea [17,18].

Many nations have gradually shown the importance of the interactions between the land and sea by comprehensively promoting the coordinated development of coastal areas [19,20]. Some researchers used input-output methods to analyze the coordinated development of economic linkages in land-sea industrial structures [21–23]. In addition, the changing environments, resources, science, and technologies of coastal areas pose challenges to developing marine economies in different regions. Therefore, marine industries should be diversified, and a complex relational network should be constructed with continental industries to facilitate flexibility in land-sea industrial development and coordination of these industries [24–26].

Some researchers have used Granger causality tests, variance decomposition analyses, and other econometric methods to test the existence of causality between land-sea industries [27–33]. Gray system theory, a degree of order model, fuzzy system theory, and an information entropy model were used to measure the correlations between different marine industrial values [30,34,35]. Meanwhile, kernel density and coupled models were used to study the spatiotemporal differentiation of land-sea industries in different regions [36–43].

Analysis shows that the research on the coordinated development of land-sea industrial structures was in the preliminary stages. Past research results can be divided into two foci. First, the utilization and management of land-sea resources in coastal areas have been analyzed from the perspective of the systems theory. Second, the mechanism(s) underlying dynamic correlations and collaborative developmental status have been quantitatively analyzed based on data-driven land-sea integration. Under the coordinated development of the land-sea industry, the development of land and sea industry has a synergistic effect and coupling effect through exploring the specific layout of the land and sea industry on the coastal zone, the comprehensive management of the coastal zone, and coastal space planning considering the development factors of the land and sea industry. Although an increasing number of research has been conducted in land-sea industrial relations from the perspective of land-sea economics, the research on land-sea economic and industrial structural linkages remains limited and scattered; the perspectives on such linkages are relatively simple, and the spatial differentiation between them is very rare. In addition, there have been few studies on the driving effect(s) of marine and continental industries over different periods, and the analyses of the effects of time differences between continental and marine economic and industrial structures based on a dynamic perspective are relatively rare.

Therefore, the research aims of this paper are adjusting and optimizing the key industrial structures in various regions by the following three points, which include understanding the developmental status of land-sea economies and industrial structures comprehensively, pointing out the problems existing in their development, and exploring the spatiotemporal differences in the linkages of land-sea economies and industrial structures. We considered three marine economic circles in China as the research objects, employed gray system and coordinated development theories as theoretical foundations, and analyzed the present situation of land-sea industrial development. We examined the dynamic differentiation and coevolution of land-sea industries in these three marine economic circles over time and space. Consequently, we provide a new perspective for studying the coordinated development of land-sea industries, with an emphasis on recommending China's overall strategy for land-sea industrial and high-quality economic development.

2. Materials and Methods

2.1. Gray Relational Model

Most researchers agree that input-output models are the main method by which internal and external linkages in economic systems may be analyzed, as other quantitative frameworks, such as econometrics and statistics, require sufficient data and are subject to other strict data requirements. Gray system theory is suitable for analyses with small sample sizes, and helps simplify calculations of economic and industrial linkages. Due to the lack of marine economic research in China, it is necessary to use a gray correlation model to analyze the relationship between marine and continental industries within and among periods. Yin et al. used the degree of convexity to develop a relevant gray correlation model that avoids the influence of the selection method of the gray model to simulate the original data, and makes the best use of the information in the sequence itself [44].

By considering the influences of the amplitude and period of a sequence of data, it has favorable (occasional) symmetry, parallelism, and uniqueness. In this study, we aim to calculate the linkages of land-sea industrial structures using both static and dynamic correlations. First, the improved reference gray correlation model, based on the degree of convexity, was used to measure the static correlation of the industrial structure. Gray time difference analysis was then used to explore the dynamic correlations between continental and marine industries in advance and by lag time.

Gray relational grade model based on convexity. Assuming that $X_0 = \{x_0(1), x_0(2), \ldots, x_0(n)\}$ and $X_j = \{x_j(1), x_j(2), \ldots, x_j(n)\}$ are characteristic behaviors of a series of data in (a,b), based on the gray relational grade model of convexity proposed by Yin et al. [44]. The gray relational degree of the improved model of X_0 and X_j is defined in Equation (1):

$$\gamma_{0,j} = \frac{1}{l}\sum_{i=1}^{l} \xi_{0,j}(i) \tag{1}$$

where,

$$\zeta_{0,j}(i) = \frac{1}{1+\alpha\left(1-\frac{\min\{C_0(i),C_0(j)\}}{\max\{C_0(i),C_0(j)\}}\right)+(1-\alpha)\left(1-\frac{\min\{|y_0(i)|,|y_j(i)|\}}{\max\{|y_0(i)|,|y_j(i)|\}}\right)}, 0 \leq \alpha \leq 1, i = 1, 2, \cdots \tag{2}$$

The length of this wave period is defined as *C*. *L* is the corresponding polyline. The wave period is shown as:

$$\hat{d}_L(L,k) \cdot \hat{d}_L(L,k+1) \leq 0, \hat{d}_L(L,k+C) \cdot \hat{d}_L(L,k+C+1) \leq 0 \tag{3}$$

The wave amplitude for sequence is y:

$$y(i) = y_{\max} - y_{\min} \tag{4}$$

where y_{max} is the maximum of all the ordinate values in $L(k,k+C)$, and y_{min} is the minimum in it.

If $\gamma_{0,i} > \gamma_{0,j}$, the relational degree of X_i, X_0 is stronger than X_j.

Gray time difference analysis. Gray time difference analysis is based on gray correlation theory, wherein the time advance and lag are added to measure the dynamic correlations between sequences. The time difference correlation analysis measures the correlation between the reference sequence and the compared sequence before or after several periods, such that k is the leading period (or lag period), K is the maximum time difference, and X_0 is the reference sequence. When $k < 0$, the compared sequence is X_i ahead of the reference sequence, X_0. When $k > 0$, it is considered to represent a lag [45]. Generally, the calculated results of this synchronous index are ±3 years. If the advance is over 3 years, it is a leading indicator; otherwise, it is a lagging indicator.

2.2. Coevolution Model

2.2.1. Degree of Relative Advantage

The formula for calculating the relative advantage of continental and marine industries can be expressed as Equation (5):

$$X_i = \frac{M_i}{L_i}(i = 1, 2, 3) \tag{5}$$

where L_i and M_i represent the shares of value added from continental and marine industries (i), respectively, in the gross economic or gross marine product. When $X_i > 1$, the development of the marine service sector has more evident industrial advantages. The differences in industrial advantage can lead to differentiated layouts among industrial structures.

2.2.2. Degree of Deviation

Deviations in industrial structures represent the coevolution among industries and provide a means of quantitatively analyzing the development of linkages between continental and marine industrial structures. The lower the deviation, the higher the degrees of coevolution among continental and marine industries. The formula for calculating the degree of deviation is given in Equation (6):

$$P = \sum_{i=1}^{3} |M_i - L_i| \tag{6}$$

2.2.3. Coefficient of Coevolution

A coefficient can describe the characteristics of coordinated development among industries and quantitatively analyze the development of linkages between continental and marine industrial structures. However, compared with the coefficient of industrial structure, the coefficient of coevolution is better understood and mutually validated, which allows the analytical results to capture the linkages more reliably within China's land-sea industrial structure. The formula for calculating the coefficient of coevolution is given in Equation (7):

$$S = \frac{\sum\limits_{i=1}^{3} M_i L_i}{\sqrt{\sum M_i{}^2 \sum L_i{}^2}} \tag{7}$$

The means of L_i and M_i in Equation (7) are the same. The coevolution coefficient of industrial structure ranges from 0 to 1; if the calculated result is equal to 1, it means that land-sea industrial structures are consistent. If the coefficient decreases gradually with time, this indicates that the synergy degree between continental and marine industrial structures is decreasing.

Economic development at the national level can be reflected in the evolution of industrial structures. According to relevant theories of industrial economics [46], there is a general rule that the evolution of land-sea industrial structures ranges from primary to intermediate to advanced.

2.3. Data Sources and Processing

According to the regional division standard of the Ministry of Natural Resources of the People's Republic of China, the Northern Marine Economic Circle in China, Shandong, Tianjin, Liaoning, and Hebei includes the Bohai Bay, Shandong, and the Liaodong Peninsula. Jiangsu, Zhejiang, and Shanghai constitute the Eastern Marine Economic Circle and include the terrestrial and marine areas along the coast of the Yangtze River Delta. The Southern Marine Economic Circle comprises Guangdong, Fujian, and Guiqiong, including the coastal area of the Pearl River Delta, which is the southernmost marine economic circle in China and the forefront of China's foreign trade. In this study, we analyze the current developmental status of the land-sea industrial structures in these three economic zones and clarify the synchronization, lag, equilibrium, and dislocation of the development of these structures.

The added values of the three continental and marine industries were chosen as the research objects, and the linkages of the land-sea economic and industrial structures of the three economic zones were compared based on historical data from 2006 to 2019. The data were extracted from the China Statistical Yearbook, China Marine Statistical Yearbook, and statistical bulletins of the relevant provinces. To counteract the effects of inflation, the data were indexed. The processed data are presented in Tables 1 and 2.

Table 1. Processed data for the added values of major marine industries in three economic circles.

Year	Primary Sector			Secondary Sector			Service Sector		
	North	**East**	**South**	**North**	**East**	**South**	**North**	**East**	**South**
2006	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
2007	117.57	117.56	125.05	117.05	116.56	112.32	121.91	119.90	118.50
2008	117.94	132.55	108.76	120.25	112.75	142.59	115.25	113.21	112.91
2009	116.74	127.79	107.80	100.54	109.65	113.33	107.64	104.64	118.27
2010	104.28	110.06	111.31	128.33	124.38	126.04	122.07	122.27	117.90
2011	128.70	108.12	114.00	117.87	113.32	111.53	116.30	114.67	114.25
2012	112.25	121.34	106.61	106.64	105.40	113.14	113.18	110.16	111.50
2013	110.85	102.24	111.83	108.35	102.04	107.16	112.10	108.76	111.64
2014	100.08	123.12	104.96	106.64	102.41	111.60	122.37	105.44	122.59
2015	98.74	117.08	110.07	99.18	106.89	106.83	103.20	109.27	111.93
2016	105.54	107.15	113.95	90.06	106.29	105.93	98.50	109.48	111.48
2017	103.26	113.40	106.08	119.04	110.95	112.57	113.68	112.69	112.06
2018	103.20	108.62	106.40	105.97	104.78	106.08	107.64	106.94	108.09
2019	102.73	108.49	106.82	105.29	106.66	108.86	106.91	108.88	110.45

Note: this paper takes 2006 as the base period and indexes the data from 2006 to 2019.

Table 2. Processed data for the added values of major land-based industries in three economic circles.

Year	Primary Sector			Secondary Sector			Service Sector		
	North	**East**	**South**	**North**	**East**	**South**	**North**	**East**	**South**
2006	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
2007	119.92	112.89	113.10	117.95	117.29	121.46	118.24	123.28	122.47
2008	116.08	112.20	117.98	123.08	115.02	113.66	119.75	119.31	116.91
2009	106.97	104.74	101.01	108.21	104.68	106.13	115.85	115.67	110.84
2010	114.79	113.90	115.21	115.83	117.79	120.97	119.55	119.76	114.80
2011	111.16	120.25	119.80	118.13	115.06	118.85	121.41	119.00	117.61
2012	109.01	107.86	107.63	108.23	105.22	106.15	114.70	111.56	111.27
2013	104.96	102.77	103.99	106.07	105.74	106.34	115.26	115.77	115.85
2014	104.19	100.85	106.94	103.35	106.22	108.42	107.31	111.35	105.90
2015	102.61	107.10	105.70	98.03	102.66	104.10	110.31	111.30	111.18
2016	98.22	103.76	110.34	97.15	107.49	107.57	106.81	113.80	113.73
2017	92.78	98.99	98.62	104.47	109.34	105.87	109.54	111.54	114.95
2018	104.50	102.18	105.74	82.81	110.80	110.00	97.57	112.22	115.75
2019	104.89	104.42	111.67	103.86	104.29	106.34	109.21	109.01	109.34

Note: this paper takes 2006 as the base period and indexes the data from 2006 to 2019.

3. Structural Feature Analysis

3.1. Continental Economic Industrial Structure

Longitudinal comparisons and the analyses of the added values of the continental industries in the three economic circles over time revealed that the Northern Marine Economic Circle (Figure 1) played a leading role in the continental secondary sector, whereas the primary sector was always in a low state of development. From 2006 to 2015, this circle presented a primary industrial pattern. In 2016, the continental service sector of the economy gradually surpassed the secondary sector, and an advanced developmental trend gradually emerged. In the Eastern Marine Economic Circle (Figure 2), the secondary and service sectors on land displayed clear advantages when compared to the primary sector. From 2006 to 2012, the industrial structure maintained a primary mode of development ("2-3-1"), and in 2013, the pattern of industrial development was upgraded to an advanced structure ("3-2-1"). The added value of the second and third continental sectors of the Southern Marine Economic Circle (Figure 3) continued to increase. From 2006 to 2014, the continental industrial structure of this circle was at an intermediate stage of development. Not until 2015 did the third continental industry rise further, finally realizing an advanced industrial structure (“3-2-1”), and the gap between the added value of the second and third sectors gradually increased.

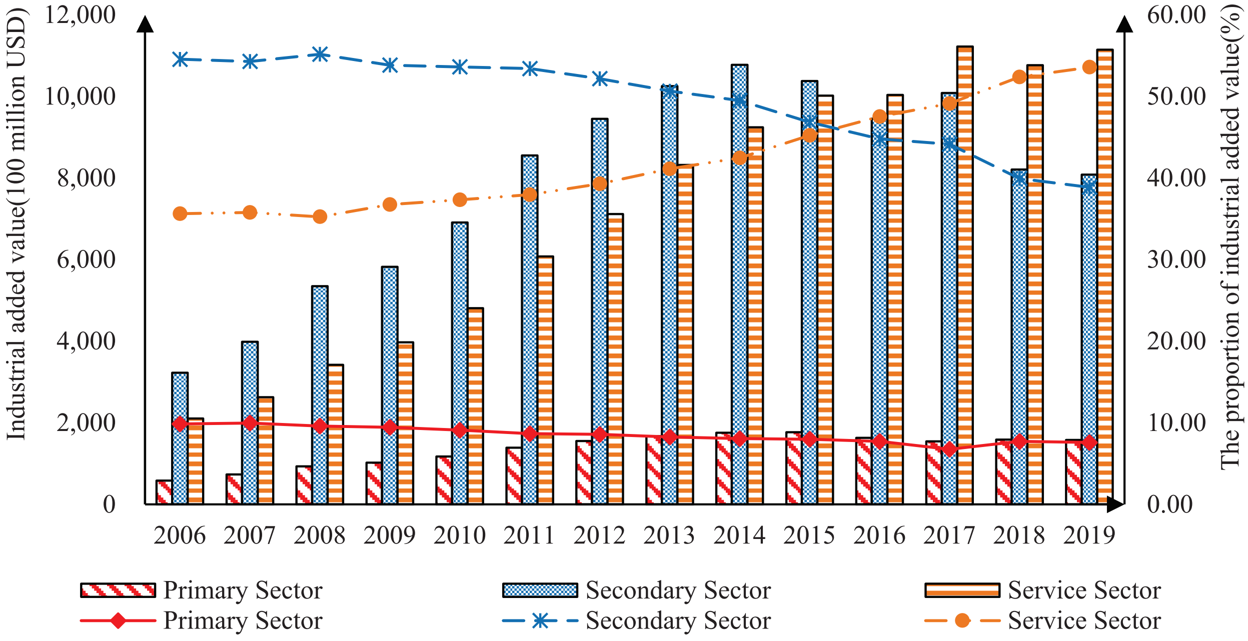


Figure 1. Industrial added values of continental three sectors in the Northern Marine Economic Circle of China (2006–2019).

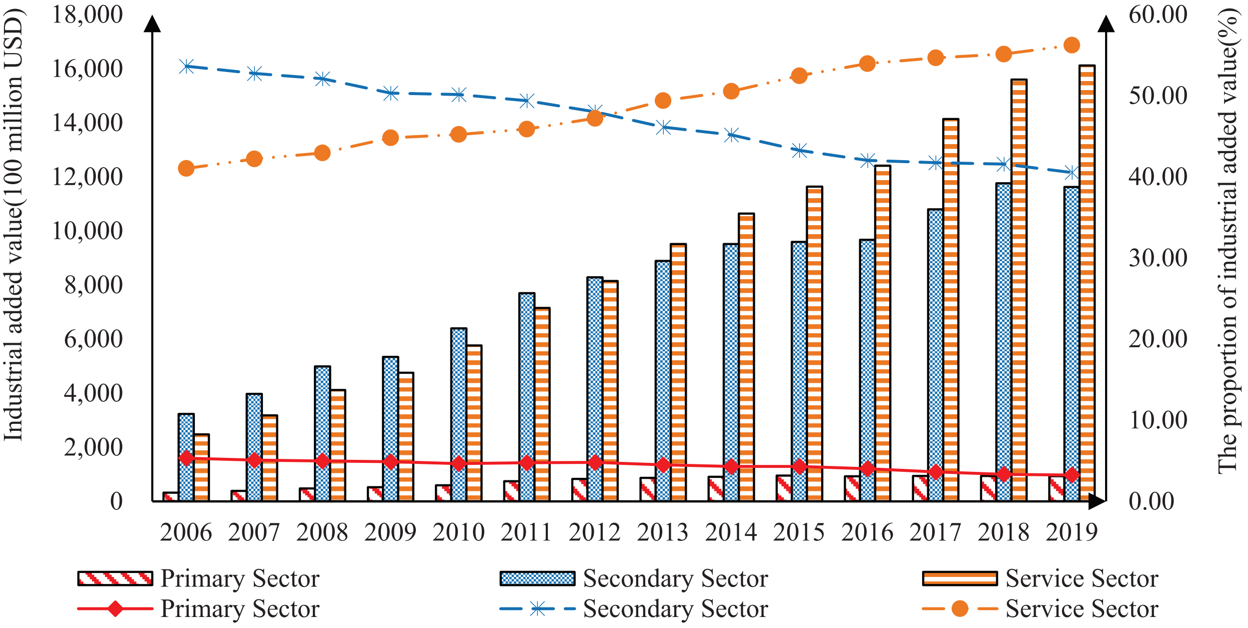


Figure 2. Industrial added values of continental three sectors in the Eastern Marine Economic Circle of China (2006–2019).

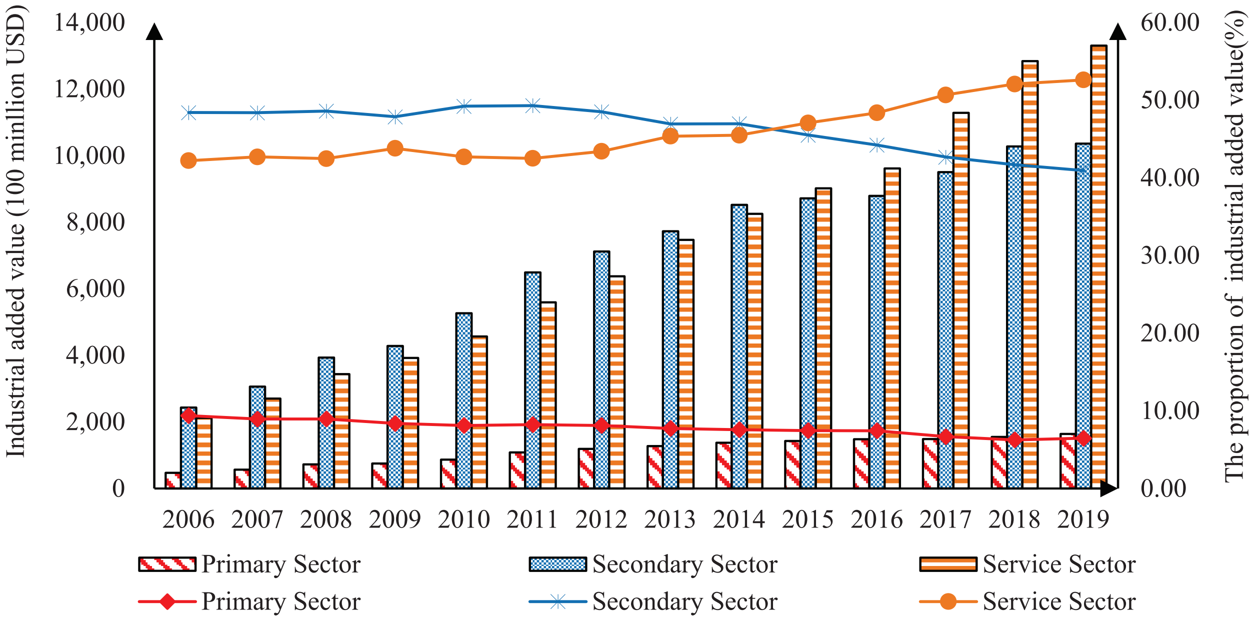


Figure 3. Industrial added values of continental three sectors in the Southern Marine Economic Circle of China (2006–2019).

3.2. Marine Economic Industrial Structure

The added values of the three marine industries in the Northern Marine Economic Circle show increasing trends to different degrees (Figure 4). Among them, the marine primary sector exhibited the smallest growth, and the added value of the marine service industry presented a positive linear trend in development. From 2006 to 2013, the marine secondary sector dominated, such that the marine industrial structure presented a primary stage of development (“2-3-1”). Since 2014, the added value of the marine service sector has continued to rise, widening the gap with the secondary sector, and an advanced (“3-2-1”) structure has gradually emerged. The added values of the secondary and service sectors in the eastern and southern economic circles (Figures 5 and 6) were much higher than those of their primary sectors, and the industrial structure has evolved to an advanced (“3-2-1”) and stable stage of industrial development.

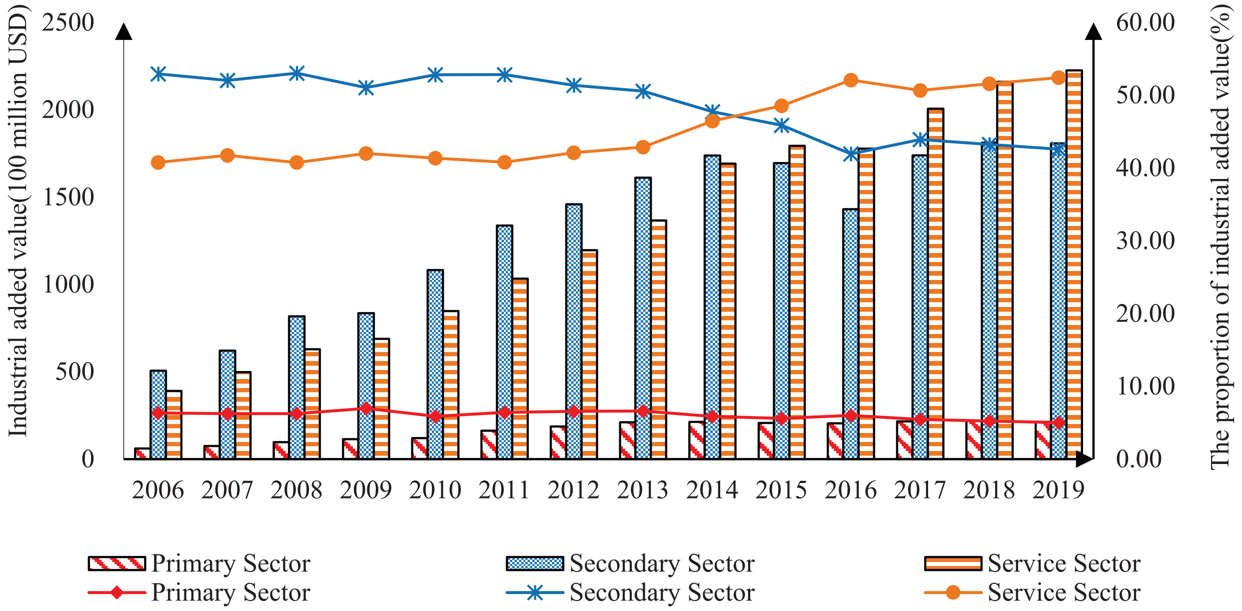


Figure 4. Industrial added values of three marine sectors in the Northern Marine Economic Circle of China (2006–2019).

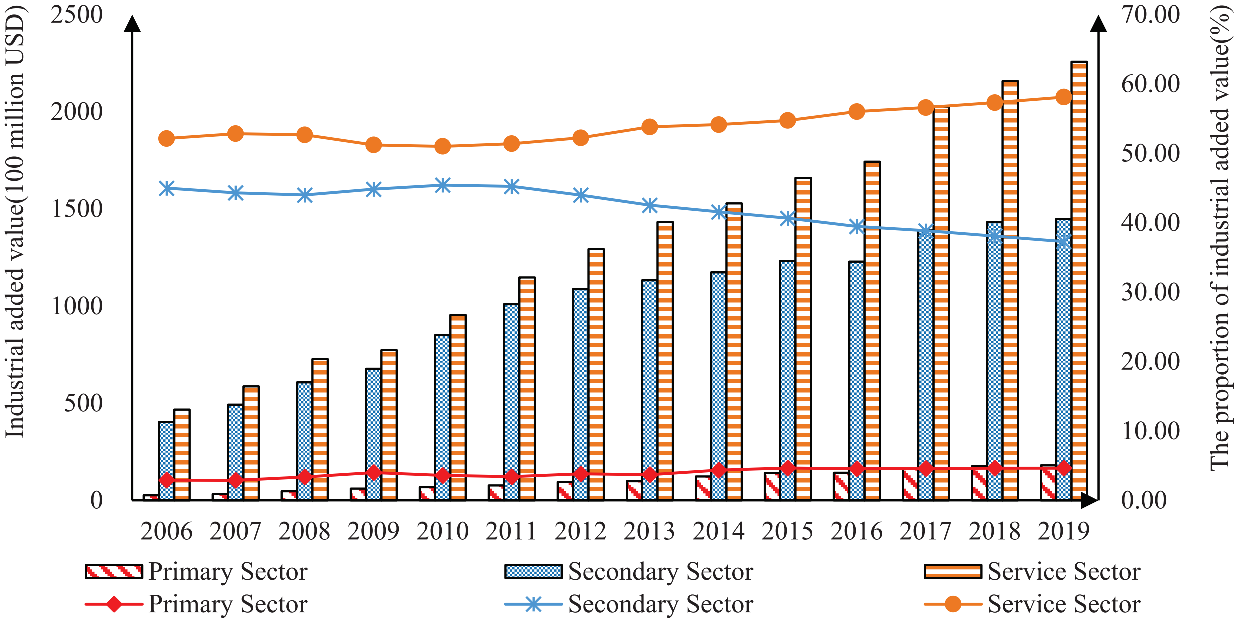


Figure 5. Industrial added values of three marine sectors in the Eastern Marine Economic Circle of China (2006–2019).

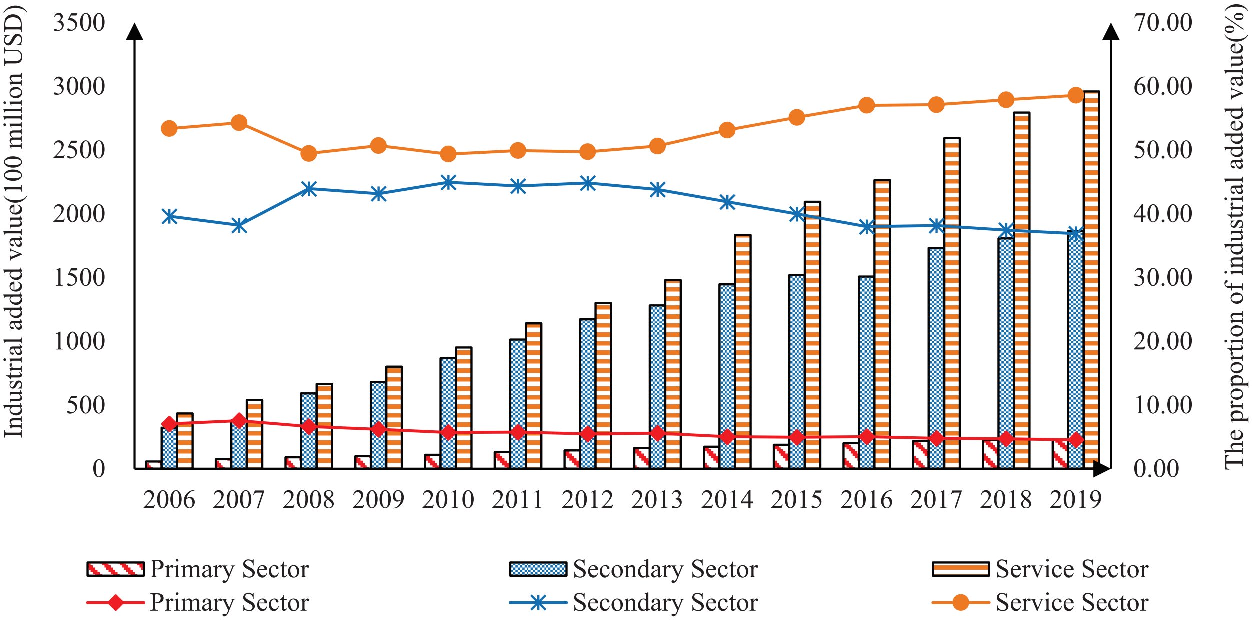


Figure 6. Industrial added values of three marine sectors in the Southern Marine Economic Circle of China (2006–2019).

3.3. Analysis of Linkage Development

Before 2014, the marine secondary sector in the Northern Marine Economic Circle accounted for a high proportion, and its Hoffman coefficient [47] was much larger than the national marine Hoffman coefficient. The marine shipbuilding industry, chemical industry, salt industry, oil, and gas industry were relatively advanced in development; the seawater utilization industry and marine biological medicine industry were also well developed. The low proportion of the marine service industry was mainly due to its low level of scientific research and the lower development of coastal tourism and marine transportation relative to the Chinese national average. Under the policy of the National 13th Five-Year Plan, and with the establishment of coastal provinces and cities in the marine economic demonstration zone and increased investment in marine science and technology, the service sector in the Northern Marine Economic Circle has developed rapidly. The development of the oil, gas, and ship industries requires advanced technologies and equipment, which provide new opportunities for developing the secondary manufacturing industry on land. Marine mining, chemical, and other industries also need the support of continental mining and metallurgical technologies. The transportation of offshore oil, gas, seawater, and marine energy resources can alleviate the crisis of increasingly depleted terrestrial resources, reduce the production costs of enterprises, and promote the development of relevant continental industries with technological progress, such as in seawater utilization. Therefore, developing the land area of the Northern Marine Economic Circle is essentially synchronized with marine industrial development.

From 2006 to 2012, the continental industrial structure of the Eastern Marine Economic Circle presented a primary (“2-3-1”) mode of development. With the rapidly developing service sector, a stable, advanced (“3-2-1”) mode developed from 2013 to 2019. Moreover, the marine industrial structure was always advanced, and the overall layout was reasonable. The industrial structure in this economic circle was upgraded and transformed in 2013. The economy of Shanghai, which is dominated by the wholesale/retail, industrial, and financial sectors, transformed the service sector within approximately 20 years. The proportions of these three industries grew from 4:65:31 in 1990 to 0.3:27.0:72.7 in 2014. To date, Shanghai has formed an industrial structure with a high-end service industry dominated by the financial and information industries. However, developing Zhejiang and Jiangsu is still dominated by traditional service industries, with industry as its main support. Shanghai and Zhejiang exhibit advanced (“3-2-1”) marine industrial structures, and their coastal tourism and marine transportation industries are highly developed. The mode of industrial structure development for Jiangsu Province is primary (“2-3-1”), mainly due to the high contributions of marine engineering, electric power, shipping, and other industries. Overall, the marine industrial structure in the Eastern Marine Economic Circle is better than that on land, and the marine economy plays a stronger role in feeding economic growth.

The land-sea industrial structure of the Southern Marine Economic Circle is like that of the Eastern Marine Economic Circle. From 2006 to 2014, the structure presented a primary (“2-3-1”) developmental pattern that gradually became advanced (“3-2-1”) between 2015 and 2019. The marine industrial structure is advanced, and the overall layout is relatively reasonable, allowing for the synchronous development of the industrial structure. The Southern Marine Economic Circle has been in an advanced stage of industrial evolution (“3-2-1”) for many years. Aided by the global economic transfer of industry in the 1980s, the Southern Marine Economic Circle formed an industrial structure dominated by manufacturing electronic and communications equipment and by the heavy chemical industry; however, with China’s accession to the World Trade Organization, the service sector of the high and new information technology industry and the modern service industry have become the pillars of this region. In 2019, the combined value added of the four marine industries, which include marine fishery, coastal tourism, marine oil and gas industry, marine electricity, and seawater utilization industry, contributed as much as 85% to its major marine industries in this economic circle.

4. Results

4.1. Internal and External Linkage Analysis

The internal and external linkage between land and sea industrial structure has two aspects in this paper. On the one hand, the internal linkage refers to the relationship between the primary industry, the secondary industry, and the tertiary industry within the land industrial system or the marine industrial system. On the other hand, the external linkage means that the land industry is the external environment of the marine industry system, and, similarly, the marine industry is the external environment of the land industry system.

4.1.1. Calculating Simultaneous Correlations

The primary, secondary, and service sectors of the three economic circles were taken as the original sequences, and the gray correlation degrees based on the convexity of the three industries on land were measured (Table 3). Table 3 shows that the highest contemporaneous correlations of the Northern Marine Economic Circle were seen between the primary marine and primary continental sectors, secondary marine sector and continental service sector, and the marine service sector and secondary continental sector.

Table 3. Gray correlations among three land-sea industries in the Northern Marine Economic Circle.

γ_{11}	γ_{21}	γ_{31}	γ_{12}	γ_{22}	γ_{32}	γ_{13}	γ_{23}	γ_{33}
0.7426	0.7288	0.6942	0.6277	0.7672	0.7254	0.6779	0.7825	0.6764

Note: γ_{ij} is the degree of gray correlation based on the convexity between the marine i and continental j industries in the same period. The values of i and j correspond to: 1 = primary sector; 2 = secondary sector; 3 = service sector.

From Table 4, it can be concluded that the primary and secondary marine sectors in the Eastern Marine Economic Circle are strongly correlated with the marine service sector. Furthermore, the marine service sector was strongly correlated with the primary continental sector in the same period. A close correlation was observed between the primary marine sector and the continental service sector in the Southern Marine Economic Circle, and between the marine secondary and service sectors and the secondary continental sectors in the same period (Table 5).

Table 4. Gray correlations among three land-sea industries in the Eastern Marine Economic Circle.

γ_{11}	γ_{21}	γ_{31}	γ_{12}	γ_{22}	γ_{32}	γ_{13}	γ_{23}	γ_{33}
0.6679	0.6539	0.6800	0.6179	0.6059	0.6654	0.7213	0.6579	0.6757

Note: γ_{ij} is the degree of gray correlation based on the convexity between the marine i and continental j industries in the same period. The values of i and j correspond to: 1 = primary sector; 2 = secondary sector; 3 = service sector.

Table 5. Gray correlations among three land-sea industries in the Southern Marine Economic Circle.

γ_{11}	γ_{21}	γ_{31}	γ_{12}	γ_{22}	γ_{32}	γ_{13}	γ_{23}	γ_{33}
0.6146	0.6663	0.6262	0.7043	0.6885	0.6310	0.7407	0.6687	0.6066

Note: γ_{ij} is the degree of gray correlation based on the convexity between the marine i and continental j industries in the same period. The values of i and j correspond to: 1 = primary sector; 2 = secondary sector; 3 = service sector.

4.1.2. Calculating Gray Time Differences

Northern Marine Economic Circle. To obtain the highest correlation in the same period, the Northern Marine Economic Circle was taken as the reference sequence three times in succession, and the gray correlations based on convexity were analyzed between the Northern Marine Economic Circle and the continental primary and secondary sector sequences when the maximum time difference was $k = 3$. According to the results in Table 6, max(β_{11}) = 0.7426, max(β_{23}) = 0.7825, both of which are $k = 0$, indicating that the interactions between the primary, secondary, and service industries in this economic circle were relatively balanced, and there was no evident driving effect. When $k = -1$, max(β_{32}) = 0.7780, indicating that the marine service sector in the Northern Marine Economic Circle plays a more significant role in supporting the secondary continental sector.

Table 6. Gray time difference correlations in the Northern Marine Economic Circle ($K = 3$).

	$k = -3$	$k = -2$	$k = -1$	$k = 0$	$k = 1$	$k = 2$	$k = 3$
β_{11}	0.6422	0.5988	0.6023	0.7426	0.6280	0.5543	0.6154
β_{23}	0.6418	0.6024	0.5844	0.7825	0.5675	0.5699	0.7681
β_{32}	0.6101	0.6820	0.7780	0.7254	0.7099	0.6805	0.5968

Note: β_{ij} represents the gray time difference between marine industry i and continental industry j, where i,j = 1,2,3 . . . , etc.

Eastern Marine Economic Circle. To obtain the highest correlation in the same period, we analyzed the correlations in gray time differences between the three marine industries in the Eastern Marine Economic Circle and the sequences of the continental secondary and service sectors, when k = 3. It can be observed from Table 7 that max(β_{13}) = 0.7213 and max(β_{23}) = 0.6579 when k = 0, indicating that there were equilibrium relationships between the primary marine sector and continental service sector, and between the secondary marine sector and continental service sector of the Eastern Marine Economic Circle. When K = 1, max(β_{31}) = 0.7499, indicating that the marine service sector in this economic circle has a stronger driving effect on primary production than its reverse effect.

Table 7. Gray time difference correlations in the Eastern Marine Economic Circle (K = 3).

	$k = -3$	$k = -2$	$k = -1$	$k = 0$	$k = 1$	$k = 2$	$k = 3$
β_{13}	0.6325	0.5500	0.6221	0.7213	0.5787	0.5967	0.5521
β_{23}	0.5976	0.6362	0.6536	0.6579	0.6203	0.6223	0.6264
β_{31}	0.5862	0.5663	0.6262	0.6800	0.7499	0.6687	0.6104

Southern Marine Economic Circle. To obtain the highest correlation in the same period, we analyzed the gray time difference correlations between the three marine industries and the continental secondary and service sectors in the Southern Marine Economic Circle. As shown in Table 8, max(β_{13}) = 0.7407 when k = 0, indicating that the interaction between the primary marine sector and continental service sector in this economic circle is relatively balanced, and there is no significant driving effect. When k = −2, max(β_{22}) = 0.7542, indicating that the secondary continental sector of the Southern Marine Economic Circle has a more significant driving effect on the marine secondary sector. When k = −1, max(β_{32}) = 0.7675, indicating that the supporting and driving effects of secondary production on the marine service sector were stronger than its reverse effect.

Table 8. Gray time difference correlations in the Southern Marine Economic Circle (K = 3).

	$k = -3$	$k = -2$	$k = -1$	$k = 0$	$k = 1$	$k = 2$	$k = 3$
β_{13}	0.5751	0.6049	0.6542	0.7407	0.6610	0.7379	0.6782
β_{22}	0.7356	0.7542	0.7452	0.6885	0.7257	0.6583	0.6489
β_{32}	0.6489	0.6198	0.7675	0.6310	0.6606	0.7070	0.5977

4.1.3. Model Results

Although the land-sea industrial structure of the Northern Marine Economic Circle has transformed into an advanced ("3-2-1") economic system, the leading advantages of the continental and marine tertiary sectors have not been given full play, due to the short formation time and the instability of the "3-2-1" structure of the marine industry. Based on our analysis of the time difference correlations of the three land-sea industrial structures in this economic circle, only the tertiary marine sector has played a major driving role in the development of the secondary continental sector. With the realization of a "3-2-1" advanced industrial structure, the ability of the land-sea economy to drive reversals in the system was weakened. The rate of development of the marine economy in this economic circle still needs to be increased to make use of the available natural resources, steadily develop the primary continental and marine sectors, accelerate the development of their secondary and tertiary sectors via gradient transfer between regions, and to stabilize the "3-2-1" industrial structure.

In the Eastern Marine Economic Circle, there are strong correlations between the primary and secondary marine industries and the tertiary continental industry, as well as between the tertiary marine industry and the primary continental industry. The continental and marine tertiary industries also play an increasingly important role. As a financial center, with the establishment of the Lingang New Area and the Shanghai Pilot Free Trade Zone, Shanghai has witnessed the coordinated development of strategic services, such as financial and computer services and storage and high-end manufacturing industries, including integrated circuits and 5G chips. Jiangsu Province, with Nanjing as its capital, is a traditional industrial base with comparative advantages in its smart power grid, information technology service industry, and high-end equipment manufacturing industry. Jiangsu has many "double first-class" universities with strong research and development capabilities and strengths, and it has been relatively easy to promote the high-quality development of continental and marine economies through scientific and technological innovation. Zhejiang Province, with Hangzhou as its capital, heavily relies on Alibaba and the "Three Reforms and One Demolition" campaign to drive lifestyle improvements through technological innovation. The continental service sector has tremendous potential for development. The prosperity index of the Port of Ningbo–Zhoushan has been rising for years, as the port infrastructure has continuously improved and the marine transportation industry has developed. As the economic belt with the most developed continental economy and the highest degree of urban agglomeration in China, the Eastern Marine Economic Circle needs to coordinate with countries across the "Belt and Road" to allocate regional resources, lead the development of marine and related industries with free trade and demonstration zones, and demonstrate with its experience for the high-quality development of national land-sea economies. According to our analyses of the time difference correlations between continental and marine industries in the Eastern Marine Economic Circle, the marine service sector strongly drives and promotes the primary continental sector. This economic circle has formed an advanced ("3-2-1") industrial structure, especially regarding marine economic development, which has strong economic feedback.

The Southern Marine Economic Circle displays the greatest correlation among the secondary and tertiary marine sectors and the secondary continental sector, primary marine sector, and continental service sector. The continental processing and manufacturing industries correspond to the marine chemical, oil, and gas industries. Furthermore, the secondary marine industry is an expansion and extension of the second continental industry, and their linkage is clear. From the Pearl River Delta economic zone to the Guangdong–Hong Kong–Macao Greater Bay Area, the regional cooperation and exchange in the Southern Marine Economic Circle has changed from a simple manufacturing industry to include financial, real estate, and other tertiary industries, driving the rapid and high-quality development of coastal tourism, marine transportation, and transportation in this economic circle. Although the land-sea industrial structure of the Southern Marine Economic Circle presents an advanced "3-2-1" pattern, the dominance of the tertiary land-sea industry is not obvious, and the interregional differences within the economic circle are large. According to our analysis of the time difference correlations between continental and marine industries in this economic circle, marine reversal is weak, and the support of the continental economy of the marine economy is prominent.

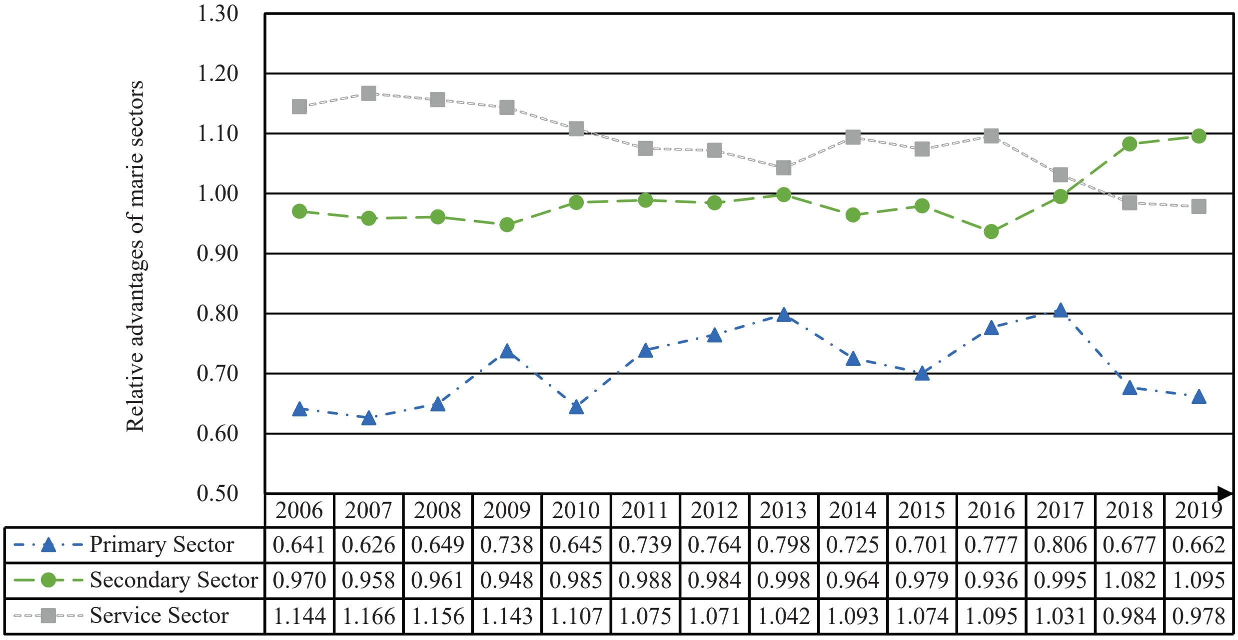
4.2. Analyses of Coevolution

Based on the deviations and coevolution coefficients between industrial structures, we analyzed the degree of coevolution between continental and marine industrial structures in three coastal economic zones from 2006 to 2019.

4.2.1. Measuring the Degree of Relative Advantage

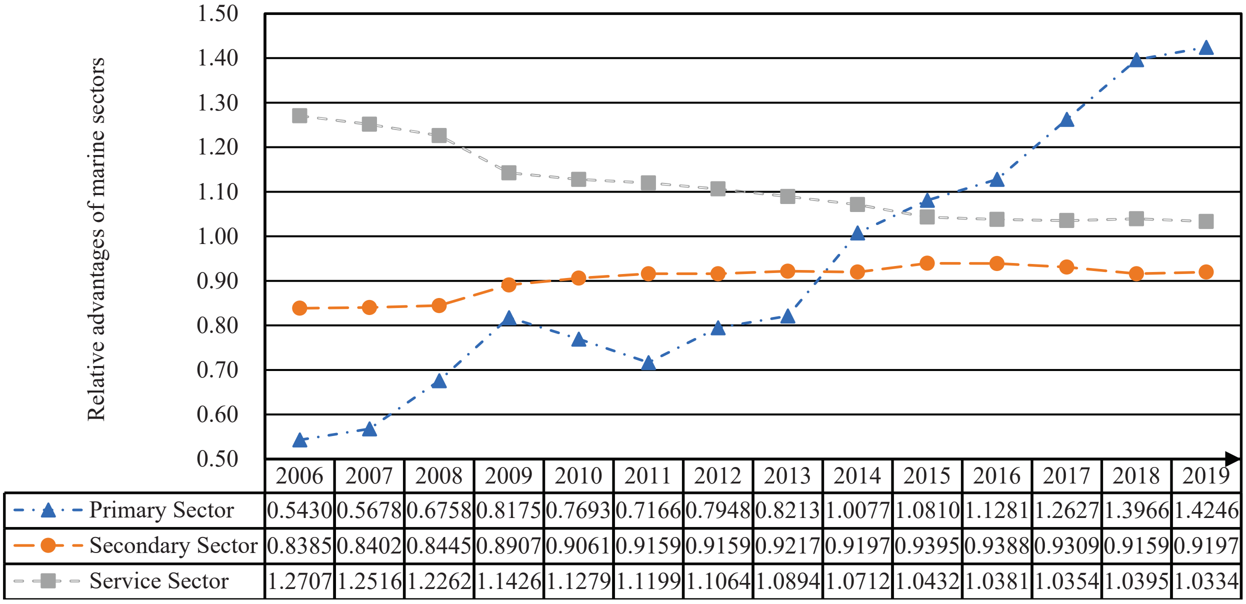
Using the Formula (3), the relative advantages of land-sea industries in the three coastal economic zones were obtained (Figures 7–9).

As shown in Figure 7, the primary continental sector in the Northern Marine Economic Circle has a comparative advantage over the other sectors. This sector formed early, and its mode of development has been stable. However, because of the pollution and the damage caused by marine disasters, the advantages of the primary marine sector have been weakened, and the relative advantages of the secondary and tertiary marine industries are nearly equal. In recent years, the advantages of the secondary continental and marine sectors have gradually exceeded those of their tertiary industries. Comparatively, marine services have more advantages; however, the effects of the continental high-tech industry were weaker than those of the marine transportation industry and feedback of coastal tourism.



	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Primary Sector	0.641	0.626	0.649	0.738	0.645	0.739	0.764	0.798	0.725	0.701	0.777	0.806	0.677	0.662
Secondary Sector	0.970	0.958	0.961	0.948	0.985	0.988	0.984	0.998	0.964	0.979	0.936	0.995	1.082	1.095
Service Sector	1.144	1.166	1.156	1.143	1.107	1.075	1.071	1.042	1.093	1.074	1.095	1.031	0.984	0.978

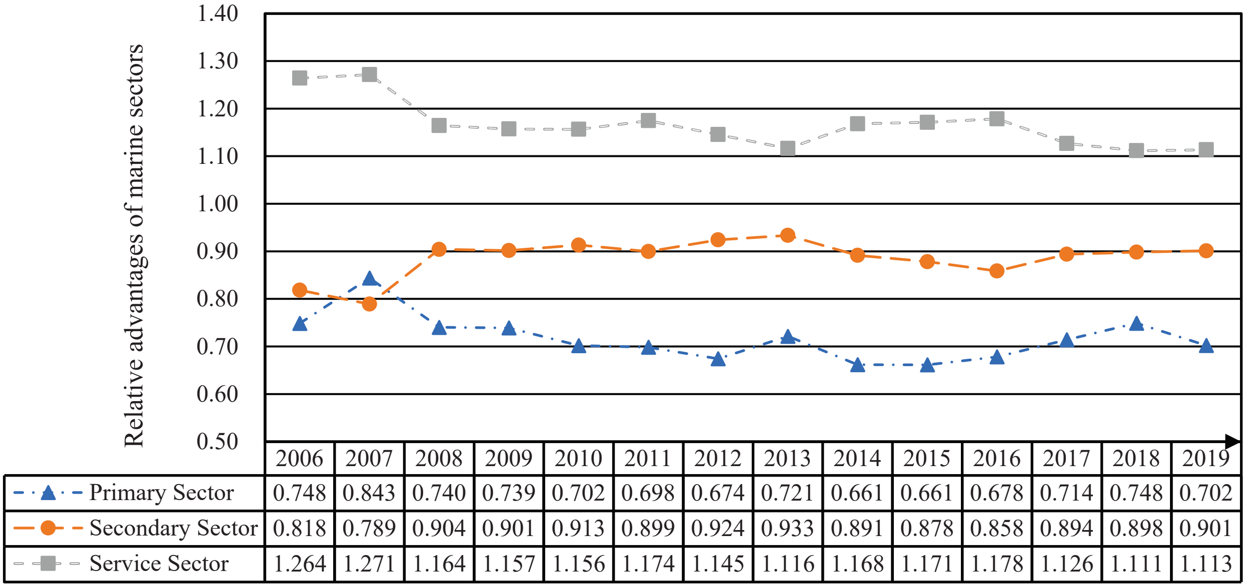
Figure 7. Relative advantages of three land-sea industries in the Northern Marine Economic Circle (2006–2019).



	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Primary Sector	0.5430	0.5678	0.6758	0.8175	0.7693	0.7166	0.7948	0.8213	1.0077	1.0810	1.1281	1.2627	1.3966	1.4246
Secondary Sector	0.8385	0.8402	0.8445	0.8907	0.9061	0.9159	0.9159	0.9217	0.9197	0.9395	0.9388	0.9309	0.9159	0.9197
Service Sector	1.2707	1.2516	1.2262	1.1426	1.1279	1.1199	1.1064	1.0894	1.0712	1.0432	1.0381	1.0354	1.0395	1.0334

Figure 8. Relative advantages of three land-sea industries in the Eastern Marine Economic Circle (2006–2019).

The relative advantages of the primary continental and marine sectors in the Eastern Marine Economic Circle are relatively weak (Figure 8), though the development of the primary continental sector is stronger. However, the advantages of the primary continental sector have gradually decreased, and the primary marine sector has varied and risen overall. In 2014, the advantages of the primary continental and marine sectors surpassed those of their secondary sectors because of the long-term balanced development of the continental and marine industrial structures. Compared to the secondary continental sector, that of the sea showed a stable upward trend from 2006 to 2010, and has remained at 0.92 since 2011. The development of the secondary continental industry began earlier in this region, which has accumulated more advanced technologies and greater investment experience, among other aspects, and therefore, it has a strong advantage when compared to other sectors. With the continuous diffusion of advantageous resources from continental industry, the advantages of the secondary marine industry have gradually improved.



	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Primary Sector	0.748	0.843	0.740	0.739	0.702	0.698	0.674	0.721	0.661	0.661	0.678	0.714	0.748	0.702
Secondary Sector	0.818	0.789	0.904	0.901	0.913	0.899	0.924	0.933	0.891	0.878	0.858	0.894	0.898	0.901
Service Sector	1.264	1.271	1.164	1.157	1.156	1.174	1.145	1.116	1.168	1.171	1.178	1.126	1.111	1.113

Figure 9. Relative advantages of three land-sea industries in the Southern Marine Economic Circle (2006–2019).

Jiangsu and Zhejiang are large provinces supported by the manufacturing industry, and the linkage between the land and sea is relatively perfect in the secondary sector of the economy, where technology and equipment are closely linked. Comparing the tertiary continental and marine sectors in the Eastern Marine Economic Circle, developing the continental sector has the advantage. In 2013, the continental industrial structure of the region shifted toward tertiary industries. With the rapid development of the secondary continental sector, the spillover of investments, technologies, human capital, and other resources have become a strong driving force for developing the secondary marine industry. Emerging marine industries have broad market prospects and are attractive to capital and talent, and have therefore developed rapidly. The gradual maturation of the marine industry has also promoted the evolution of continental industrial structures. This study infers that the marine service sector has a stronger feedback effect; thus, by 2015, the relative advantages of the primary continental and marine sectors exceeded those of their tertiary sectors.

As shown in Figure 9, the development of primary industries in the Southern Marine Economic Circle is dominant and that of the primary marine sector has gradually slowed, largely due to the frequent occurrence of natural disasters, such as storm surges, in this region. The development of the secondary continental sector is stronger than its marine equivalent. The relative advantage of this industry fluctuated slightly from 2008 to 2019; however, it remained stable overall, and the development trend is similar to that of the Eastern Marine Economic Circle. The technological diffusion brought about by the development of the manufacturing industry in the secondary continental sector is evident. Compared with the continental economy, the tertiary marine sector in the Southern Marine Economic Circle has been strongly developed, similar to that in the Eastern Marine Economic Circle.

Comprehensive analyses of the relative advantages of the three studied marine economic sectors are shown in Figures 7–9. The advantages of continental and marine industries in the three regions display the same characteristics, wherein the tertiary continental and marine industries have the greatest advantages overall, followed by the secondary, and lastly, the primary industries. The relative advantages of the tertiary continental and marine industries were all >1 every year, indicating that the tertiary industry has the greatest absolute advantage. The relative dominance of the continental, marine, and secondary sectors of the economy in each year was ~1. In recent years, because of the development of the secondary marine industry, its dominance has been >1, but with fluctuation around 1, indicating that the secondary marine and continental sectors in the three regions are roughly equal, whereas the secondary continental sector has a slight advantage. The comparative advantages of the primary continental and marine industries were >0.6, except in individual years, which indicates that primary continental industries have advantages over their marine counterparts. Nevertheless, different trends were observed among the three regions, with a variable rising trend in the Northern Marine Economic Circle, a rapid upward trend in the Eastern Marine Economic Circle, and a variable downward trend in the Southern Marine Economic Circle. The dominance of the Eastern Marine Economic Circle exceeded a value of 1 for the first time in 2014 (=1.008) and an increase of 23.17% from 2013, indicating the strong development of the primary marine sector in this region.

4.2.2. Measuring the Degree of Deviation

The degrees of deviation between continental and marine industrial structures in the three coastal economic zones were obtained using Equation (4) and are shown in Figure 10.

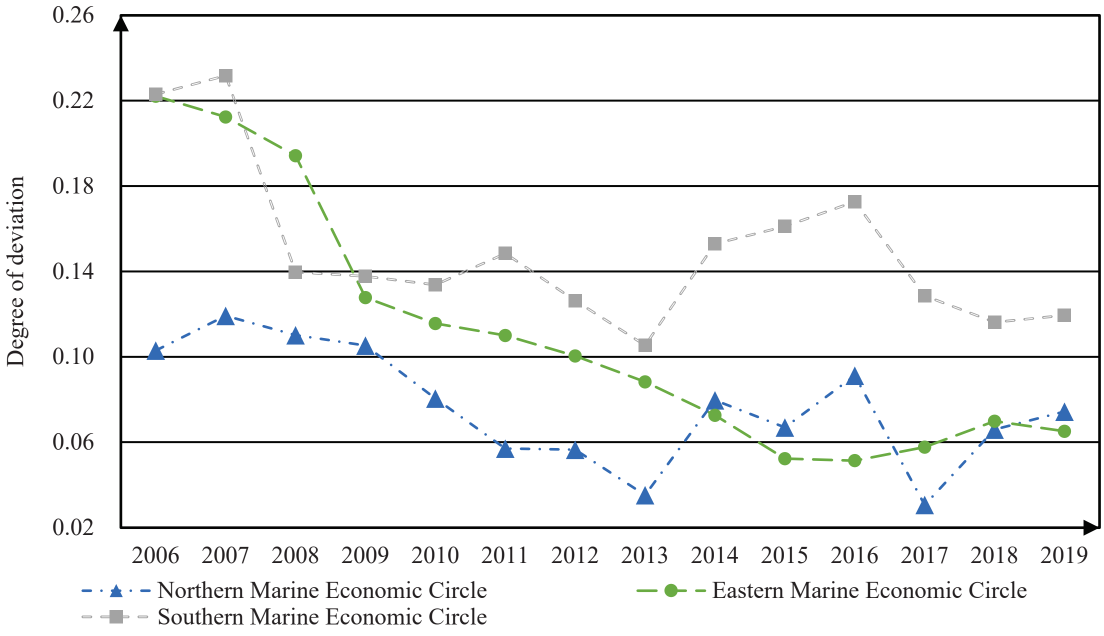


Figure 10. Degree of deviation among the industrial structures of three coastal economic circles (2006–2019).

As shown in Figure 10, an overall downward trend was observed in the degree of deviation between the structures of continental and marine industries in the three coastal economic zones; this indicates that the development of linkages and convergence in their industrial structures have strengthened over time, and the unified industrial structure is developing to a higher level. In addition, there was a consistent and substantial decline in 2008, and the effects of policies were evident. Before 2014, the deviation between the industrial structures in the Northern Marine Economic Circle was the lowest among the three regions, and the continental and marine industrial structures were the most closely linked.

Since 2009, the Eastern Marine Economic Circle has exhibited a rapid and nearly linear decline in industrial structure deviation. In 2013, the simultaneous development of continental and three marine industrial structures was achieved and the overall development of the secondary sector of the economy in the Eastern Maritime Economic Circle is relatively stable. The gap in the relative advantages of the industries is relatively small, which has resulted in a reduction in the degree of deviation between industries. Between 2014 and

2017, this region had the lowest degree of deviation in industrial structures among the three economic circles.

The absolute degree of deviation in the industrial structures of the Southern Maine Economic Circle region after 2009 was higher than that in the Eastern Marine Economic Circle. This was due to the slow speed at which this region's continental industrial structure was transformed, upgraded, and synchronized with the development of the marine industrial structure (in 2015). In addition, the tertiary continental sector developed rapidly via accumulation, resulting in a high degree of deviation between continental and marine industrial structures. In recent years, with the Chinese government promoting economic and industrial coordinated development, the gap in the industrial structures of the three marine economic zones has gradually narrowed.

4.2.3. Measuring the Coefficient of Coevolution

Accordingly, the coefficients of coevolution between continental and marine industrial structures in the three coastal economic zones were obtained (Figure 11).

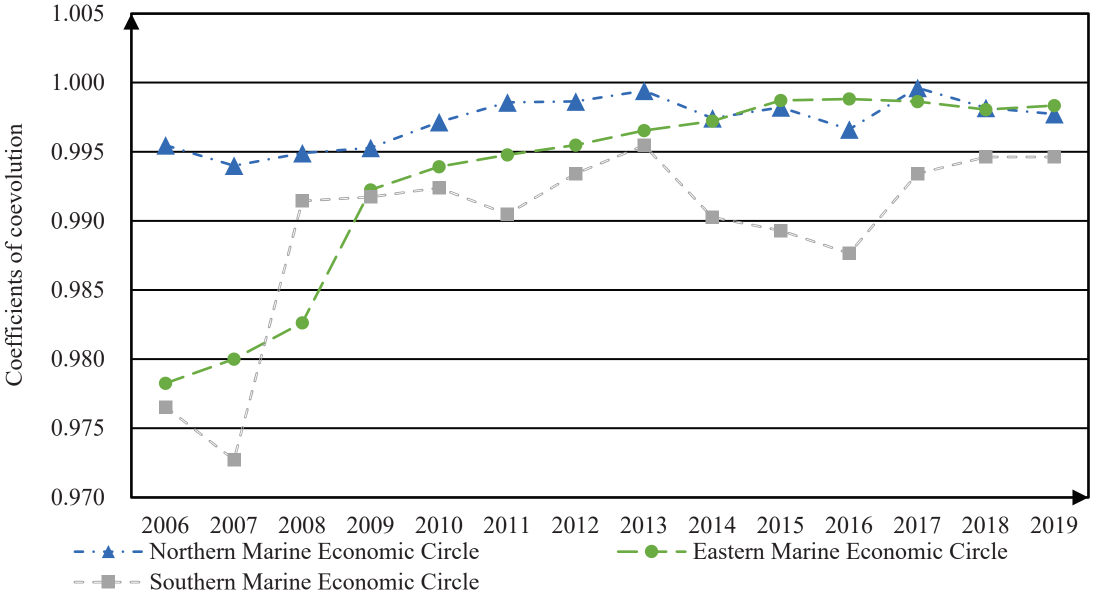


Figure 11. Coefficients of coevolution among the industrial structures in the three coastal economic zones (2006–2019).

The coordination (coevolution) coefficient of industrial structures in the Northern Marine Economic Circle revealed a high level of coordination, and the trend in linkage development from 2006 to 2019 was relatively stable. The land-sea industrial structure maintained a high level of consistency, and the layout changed from primary ("2-3-1") to advanced ("3-2-1"). After the financial crisis in 2008, both the eastern and the southern marine economic circles seized the opportunity to achieve a high degree of unity in the development of their industrial structures and an advanced ("3-2-1") layout was realized after the recovery and adjustment period. However, between 2014 and 2016, the degree of deviation in the industrial structures of the Southern Marine Economic Circle was relatively high, which made the coordination coefficients of these years change considerably and caused clear variability. With the stabilization of the deviations between industrial structures, the coordination coefficient of the land-sea industrial structure in this region gradually recovered and stabilized.

5. Conclusions

Based on the structural feature analysis of land and sea industry, statistical and gray systems methods were comprehensively applied to analyze the spatiotemporal differences in the linkages of land-sea economic and industrial structures in three coastal economic zones. The development of linkages among three industrial structures in the three coastal economic zones of China from 2006 to 2019 was measured regarding the synchronization and lag in the development of the industrial structure itself, equilibrium and dislocation, the internal and external linkages of the industrial structure, and its coordinated evolution.

Synchronization and lag in the development of the industrial structure. The layout of the industrial structure of China's three coastal economic zones still requires improvement, and the level of development among regions differs markedly. In 2016 and 2014, the land-sea industrial structure of the Northern Marine Economic Circle changed from primary ("2-3-1") to advanced ("3-2-1"); however, the advantages of the tertiary sector were unclear. From 2006 to 2012, the continental industrial structure of the Eastern Marine Economic Circle presented a primary pattern ("2-3-1"), which gradually became advanced ("3-2-1") between 2013 and 2019. The marine industrial structure of this economic circle is in an advanced stage of development ("3-2-1"), and the overall layout is reasonable. From 2006 to 2014, the continental industrial structure of the Southern Marine Economic Circle exhibited an advanced pattern ("3-2-1"), which was transformed between 2015 and 2019. The marine industrial structure has maintained an advanced ("3-2-1") mode of development, and the overall layout is reasonable. Both the eastern and southern economic circles have been developing in dislocation for many years, while also having realized the synchronous development of continental and marine industrial structures.

Spatiotemporal differences in the internal and external linkages of China's land-sea industrial structure. Although the land-sea industrial structure of the Northern Marine Economic Circle has changed from the "2-3-1" type to the advanced "3-2-1" type, the secondary and tertiary marine industries in this economic circle were the most strongly correlated with the secondary and tertiary continental industries; however, the current level of economic development in this region has not yet given full play to the advantages provided by the tertiary continental and marine industries. While an advanced stage of synchronous development has been realized, the comparative advantages of the industrial structures are not outstanding, and the transformation and upgrade of the industrial structure and high-quality development of continental and marine industries should be improved.

The tertiary continental sector in the Eastern Marine Economic Circle has played an increasingly important role in the economic development of this region. Moreover, the primary and tertiary continental industries have had strong positive effects on the primary and tertiary marine industries. The Eastern Marine Economic Circle has formed an advanced ("3-2-1") industrial structure, especially regarding its marine economic development, which has a strong role in the developmental feedback of this economy and is suitable for use as a reference. Although the Southern Marine Economic Circle has achieved an advanced ("3-2-1") land-sea industrial structure, due to pronounced differences in regional development, the dominant advantage of the tertiary continental and marine sectors has not been given full play, and the role of the marine economy is weak.

Differences in the coevolution of industrial structures. The coordination (coevolution) coefficient of the industrial structure in the Northern Marine Economic Circle shows a high degree of coordination, and the development of economic and industrial linkages was stable from 2006 to 2019. The land-sea industrial structure has exhibited an advanced ("3-2-1") layout, but with substantial room for improvement. The Eastern Marine Economic Circle and the Southern Marine Economic Circle have both achieved a high degree of coordination in the development of their industrial structures, reaching an advanced ("3-2-1") model of industrial development. However, the Eastern Marine Economic Circle has a weak marine economy, and the development of the secondary and tertiary marine industries should be strengthened to promote the balanced development of the land-sea economy in this region.

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