How does index-based insurance support marine disaster risk reduction in China? Evolution, challenges and policy responses

Abstract: Marine disaster index insurance (MDII) has been recognized as an excellent emerging instrument for marine disaster risk management in coastal regions due to its dual advantages of immunity against moral hazard and adverse selection, alongside immediate compensation. This paper tracks the evolution history and reviews the pilots of China's marine disaster index insurance since 2013. After nearly a decade of development with government policy support, China has made great progress in piloting MDII against marine disaster risks. However, several deficiencies have been observed in reviewing the MDII pilots in China. There are also operational challenges of formulating and implementing MDII for its wide adoption. This paper recommends the following improvement strategies: improving the market ecosystem and regulatory system for MDII, enhancing the capability of MDII insurers to deal with instant massive claims, diversifying the channels and forms of subsidy policies for MDII, promoting public awareness of using MDII to manage marine disaster risks, and designing scientific MDII products.

Keywords: Marine disaster index insurance; China; Policy evolution; Subsidy scheme; Challenges; Potential policy responses

1 Introduction

The safety and stability of coastal areas have always been the core element for promoting social and economic progress in various coastal countries, especially in China, a large country with a long coastline and a growing marine economy. In 2021, the total value of production in the marine economy in China was CNY 9038.5 billion, accounting for 15% of the coastal area's GDP. Meanwhile, China is one of the countries suffering marine disasters (Zhao et al., 2020), which are intensified by frequent extreme events recently (Fang et al., 2017). As shown in Fig 1 and Fig 2, during 2009-2021, marine disasters caused direct economic losses of CNY 114.047 billion and 757 deaths in China. In 2019, China suffered huge direct losses of CNY 11.703 billion and 22 deaths (including missing) from marine disasters, including the 16 storm surges with direct economic losses of CNY 11.638 billion. Specifically, Guangdong, Zhejiang, Fujian, Shandong, where the marine economy is well developed, have suffered more severely from marine disasters (Zhang et al., 2021). As with other coastal countries, China attaches high priority to defending coastal areas from attack by marine disasters, where the risk management arrangement is a crucial part of this direction (Poo et al., 2021). However, a survey jointly conducted by the State Oceanic Administration, the People's Bank of China, and the National Development and Reform Commission in 2017 found that marine disaster insurance in China is inadequate, so the effective marine disaster risk management scheme is still in short supply. The survey findings highlight the need for government to explore ways and support to improve the risk management system for marine disasters in coastal areas, among which the support of

marine disaster insurance is an important part of this process.

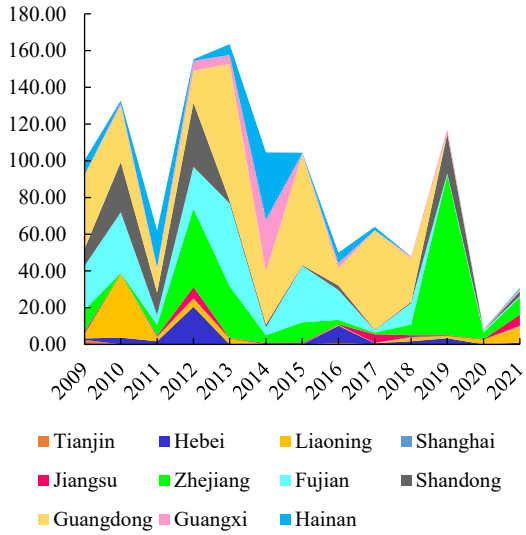


Fig 1 Direct economic losses resulting from marine disasters in 11 coastal areas of China

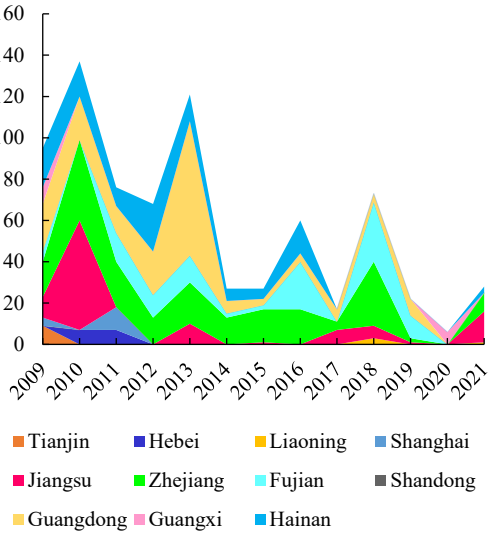


Fig 2 Deaths (including missing) resulting from marine disasters in 11 coastal areas of China

Insurance is widely used around the world as an effective financial tool to mitigate the risks of natural disasters, with index-based insurance recognized as an important and emerging one (Pompe and Rinehart, 2008; Mushtaq et al., 2020). Index-based insurance is an insurance product based on the index composed of a parameter or a combination of the parameters of a specific event that occurs within a pre-agreed period and insurance area (Rao, 2010). Currently, the widely used index-based insurance is weather index insurance, which serves risk management for agriculture, such as rainfall index insurance, temperature index insurance, and wind force index insurance (Wang et al., 2018; Torabi et al., 2019; Xue et al., 2022). Marine disaster index insurance (MDII) is an innovative application of index-based insurance aiming to manage the risk of marine disasters.

Different from traditional insurance, MDII is a standardized contract in which the claims are based on values obtained from an index that serves as a proxy for losses

rather than upon the assessed actual losses of policyholders (Wang, 2016). Benefiting from its index-based trigger scheme, MDII eliminates the claims process of traditional insurance, including the procedure of travelling to the attacked spot to investigate and access the losses, thereby avoiding fraud issues and ensuring the effectiveness of the insurance (Gommes and Kayitakire, 2014). Also, MDII could provide quick support for policyholders as the insurer will pay the claims to policyholders immediately once the index is triggered, eliminating the investigation assessment of the loss. Thus, the instant availability of claims provides timely support for the policyholders to recover damaged assets and livelihoods in coastal areas from marine disasters (Norton et al., 2014). Moreover, the COVID-19 epidemic, as a sudden disaster shocking most human activities (Xu et al., 2021; Xu et al., 2022), highlights the advantages of MDII as its index-based trigger scheme allows the claims processed free of person-to-person contact physically. In addition, MDII also provides support for the maintenance of the ecosystem service values in coastal regions, especially for marine ecological resources such as mangroves and seagrasses, which are recognized as carbon sinks and safeguards for marine disasters (Deb and Mandal, 2021; Fanning et al., 2021). Precisely matched MDII for these resources can provide them with accurate and timely risk management, contributing to the conservation and sustainable development of the ocean and coastal environment. In general, MDII provides new ideas for the development of accurate marine disaster risk management in China as a supplement to traditional marine disaster insurance. It is timely with an urgent need for China to bridge the capacity gaps that inhibit risk reduction management.

Index-based insurance serves a variety of policy purposes in many countries, and so does China, employing marine disaster index insurance (MDII) to improve the support for the safety and stability of coastal areas. The first MDII in China was initiated in 2013 on a small scale in Dalian, which only serves the Mariculture of Zhangzidao Group. After nearly a decade of evolution, kinds of MDII products have been proposed and piloted, such as wind index insurance for mariculture, red tide index insurance, typhoon index comprehensive insurance, wind index insurance rubber tree, etc. Despite the various pilots and policies for promoting MDII launched in China's coastal areas, MDII have achieved very limited success in recent years. For instance, in the pilot of wind index insurance for scallop farming in Hebei in 2016, only accepted by 18 farmers among the 300 farmers. In the pilot of the wind index insurance for Zhangzidao Group started in 2013, only three insurance firms were engaged in the business, and it was terminated after a large claim of over 80 million CNY in 2016 (Xue et al., 2022). Indeed, MDII in China is trapped in the dilemma of insufficient demand and inadequate supply, leaving the majority of China's coastal areas exposed to marine disaster risks. The sharpest key to tackling the dilemma is to map out the current situation of MDII. However, an understanding of the evolution, experience, and characteristics of MDII in China with clarity is remaining lacking currently.

To fill this gap, this paper provides an overview of the past and present of MDII in China. On this basis, this paper contributes to the stock knowledge by identifying the challenges and limitations in the development of MDII in China, which plays a crucial but unclear part in the operations of MDII. Furthermore, this paper advances the

knowledge of the potential policy responses and political countermeasures to close the gap in promoting the MDII in China. The findings of managerial insight are significant for both academics and practices, as it sheds light on the clues to the dilemma that the MDII is trapped in, as well as the potential solutions to promoting MDII operations for the risk reduction of marine disasters in coastal areas.

The rest of the paper is structured as follows. Section 2 reviews the evolution of China's marine disaster index insurance in the past decades. Section 3 illustrates the various products of MDII in the pilots of MDII in China. Section 4 analyses the characteristics and challenges of MDII in China. Section 5 investigates the potential policy responses of MDII in China. The conclusion is presented in Section 6.

2 Evolution of China's marine disaster index insurance

In the past decades, the Chinese government has issued a series of policies regarding the MDII. Guided by these policies, marine disaster index insurance is growing rapidly. This paper analyzes the evolution of MDII in China by summarizing the relative policies and evolution of MDII pilots. The timelines of the evolution of MDII in China are shown in Fig 3.

It can be seen from Fig 3 the MDII has been growing rapidly in the last decade. Overall, taking the range of industries covered by MDII as the basis, the evolution of MDII in China can be summarized in three stages, which include the germination stage, the preliminary development stage of MDII in aquaculture, and the comprehensive development stage of MDII in multi-industries.

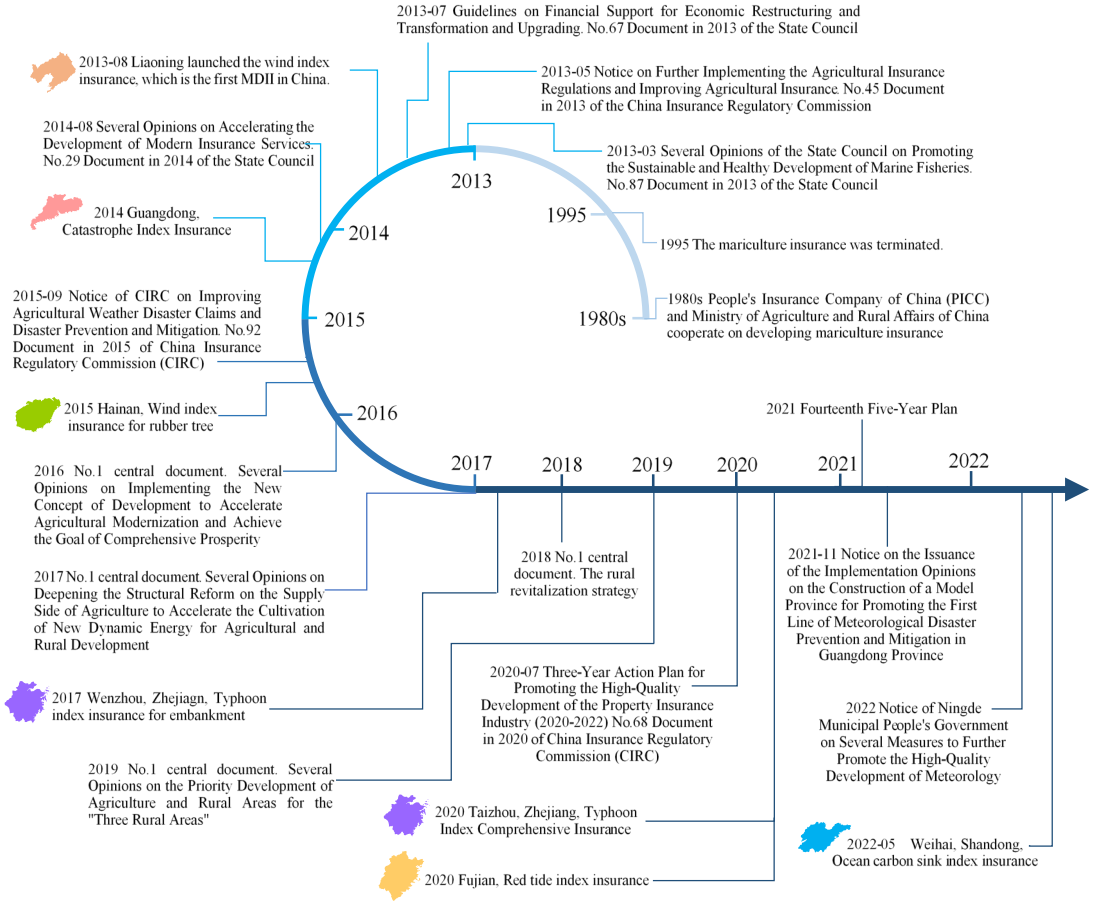


Fig 3 Timeline of the evolution of China's marine disaster index insurance

2.1 Stage 1. Germination stage

Generally, the existing marine disaster insurances in China are mostly serving the development of fisheries in the progress of blue granary, which aims to improve the output and quality of marine aquatic products while maintaining the protection of the marine ecosystem (Han and Li, 2015; Du and Cao, 2022). To support the sustainable and stable development of the blue granary, the People's Insurance Company of China (PICC) has been cooperating with the Ministry of Agriculture and Rural Affairs of China to develop mariculture insurance since the 1980s. From 1982 to 1995, the total insurance premiums amounted to USD 1.12 million, while the total claims amounted

to USD 2.2 million (FAO, 2017). The loss ratio of 197% caused the PICC to suffer high costs and subsequently terminate the project. Since then, the fishery industry in China has entered a stage without any protection from insurance. To overcome this obstacle, in March 2013, the "*Several Opinions of the State Council on Promoting the Sustainable and Healthy Development of Marine Fisheries*" issued by the State Council of China required financial institutions to research and improve the policies to support fishery insurance and launch mariculture insurance activities. This policy improved the safeguard of China's fisheries' sustainable development. Followed in May 2013, the *Notice on Further Implementing the Agricultural Insurance Regulations and Improving Agricultural Insurance* issued by the China Insurance Regulatory Commission emphasized that insurance firms are encouraged to actively research and develop new products such as weather index insurance with the view to fulfill the growing needs of farmers for risk protection. In July 2013, this initiative is highlighted again by the State Council of China in *The Guidance on Financial Support for Economic Restructuring and Transformation and Upgrading*. In August 2013, Liaoning led the launch of the wind index insurance for Zhangzidao Group, by which PICC Property and Casualty Co., Ltd. offered a CNY 400 million policy to Zhangzidao Group for its mariculture in Dalian and Shandong (Tong, 2013). This is the first MDII product in China, from which index-based insurance has begun to be used in China for reducing the risks of marine disasters.

2.2 Stage 2. Preliminary development stage of MDII in aquaculture

To further guide the development of MDII in China, multiple sectors have issued

policies to support the initiation of pilots. For instance, in August 2014, the State Council of China issued *Several Opinions on Accelerating the Development of Modern Insurance Services*, which emphasized once again the intention to explore emerging insurance products such as weather index insurance. Following the direction, the China Insurance Regulatory Commission (CIRC) issued the *Notice of CIRC on Improving Agricultural Weather Disaster Claims and Disaster Prevention and Mitigation* in September 2015, which indicates that the piloting of emerging weather index insurance and supplementary protection productions should be accelerated to meet the diversified insurance demands of new agricultural producers and operators. Following the pilot in Liaoning and supported by government policies, there is a growing number of index-based insurance products for mariculture launched in coastal regions. For example, in 2015, Liaoning was the first to launch weather index insurance for sea cucumber farming, and Taiping Property Insurance Co., Ltd. Shandong Branch launched wind index insurance for scallop farming. In the same year, Guangxi launched pilots of wind index insurance for shrimp and oyster mariculture in Fangchenggang, Beihai, and Qinzhou; and the first wind index insurance for deep-water netting mariculture was signed. In 2016, Laoting in Hebei was identified by the Ministry of Agriculture and Rural Affairs of China as the first pilot county in Hebei for weather index insurance for scallop farming. In 2017, the Fujian Fisheries Mutual Insurance Association joined hands with commercial insurance firms to launch a typhoon index insurance for mariculture. In February 2021, the first commercial wind index insurance for oyster farming in Guangdong was proposed in Jiangmen. Except for wind index insurance,

red tide index insurance is beginning to be piloted. In April 2020, a pilot red tide index insurance was launched in the sea areas of Putian Nanri Island and Pingtan Comprehensive Experimental Zone in Fujian.

2.3 Stage 3. Comprehensive development stage of MDII in multi-industries

In addition to mariculture, index-based insurance for other industries in the areas of vulnerability to marine disasters is growing. For example, in 2015, the wind index insurance for rubber trees was piloted in Hainan. In 2017, Wenzhou signed a typhoon index-based insurance contract for embankments defending against marine disasters, aiming to protect embankments, sea ponds, sluices and weirs no higher than level 3-5. Along with the industry-specific MDII pilots, China's coastal regions are beginning to explore the comprehensive MDII, intending to fully exploit the benefits of index-based insurance in disaster prevention and mitigation. Accordingly, since 2014, Guangdong has been piloting catastrophe index insurance, which mainly protects against the risk generated by typhoons, heavy rainfall, and earthquake. By 2020, the pilots were extended to 17 cities in Guangdong, including Shanwei, Zhanjiang, Zhaoqing, Yangjiang, etc. In August 2020, Huangyan, which is a district located in Zhejiang that always suffers from the attacked of typhoons, signed a comprehensive typhoon index insurance contract with PICC Property and Casualty Co., Ltd. and Ping An Property and Casualty Co., Ltd., marking the official launch of typhoon index comprehensive insurance in Zhejiang. In addition, in May 2022 China's first marine carbon sink index insurance contract was signed in Weihai, Shandong, which aims to facilitate the development of the blue carbon industry. It can be seen that MDII pilots launched in

China are expanding in scale and scope. MDII has a promising future as essential for developing catastrophe insurance against frequent marine disasters. The "*Three-Year Action Plan for Promoting the High-Quality Development of the Property Insurance Industry (2020-2022)*" issued in August 2020 emphasized the improvement of the catastrophe insurance system one more time. Meanwhile, "the development of catastrophe insurance to improve disaster prevention, mitigation, resistance, and relief capabilities are outlined in the *Fourteenth Five-Year Plan*. From then on, MDII in China entered into a stage of fast development with the support of these policies.

3 China's marine disaster index insurance products

Generally, the MDII mainly includes three categories: MDII for mariculture, such as typhoon index insurance for abalone farming; MDII for non-mariculture in coastal regions, such as wind index insurance for rubber trees; comprehensive MDII, such as catastrophe index insurance. Since the piloting of wind index insurance for mariculture in Liaoning in 2013, an increasing number of China's coastal regions have launched projects of MDII pilots according to their demand for risk management. MDII is advancing relatively quickly in China, with expanding scales and an increasing variety of products. A summary of MDII products from pilots in China is outlined in Table 1.

As can be seen from Table 1, after nearly a decade of development, various MDII pilots of MDII have been launched in coastal regions in China, indicating that China has achieved initial success in developing MDII. These pilots reveal four characteristics of the MDII's progress in China.

(1) Mariculture is the focus of the majority of the MDII pilots in China, which

involve a range of aquatic species that are sensitive to marine disasters, such as sea cucumber, seaweed, kelp, oyster, and abalone. In the pilots, MDII products are designed according to their exposure characteristics as consequences of anticipated attacks by marine disasters.

Table 1 MDII products from the pilots in China

Time	Insurance firm	Pilot areas	Index	MDII products
2013	PICC Property and Casualty Co., Ltd.	Changhai, Dalian; Rongcheng, Shandong; Long island, Shandong	Wind speed	Wind index insurance for Zhangzidao Group
			Wind speed	Wind index insurance for kelp, scallops, oysters, raft farming
2015	Taiping Property and Casualty Co., Ltd.	Yantai, Weihai, Dongying, Rizhao, Weifang, etc.	Typhon	Typhoon index insurance for abalone farming in Rongcheng
			Wave Height	Wave height index insurance for offshore and deep sea cage farming on Long Island
2015	PICC Property and Casualty Co., Ltd.	Fangchenggang, Beihai and Qinzhou in Guangxi	Wind speed	Wind index insurance for big oyster farming
2015	PICC Property and Casualty Co., Lid. Hainan Branch	Xinglong Overseas Chinese Farm, Rubber Company, Wanning, Hainan Province	Wind speed	Wind index insurance for rubber tree
2016	China Fishery Mutual Insurance Association; Hebei Fishery Mutual Insurance Association; AnHua Agricultural Insurance Co., Ltd.	Laoting, Heibei	Wind speed	Weather index insurance for scallop farming
2017	Swiss Re-insurance Company; China Ping An Property Insurance co., Ltd.	Jiangsu, Zhejiang, Shanghai, Fujian, Guangdong, Shandong, Guangxi, Hainan	Wind speed	Typhoon Index Insurance
2017	China Pacific Property Insurance Co., Ltd. Ningbo Branch	Hepu and Gaotang in Zhejiang	Wind speed	Wind index insurance for seaweed farming
2017	China Life Property Insurance Co., Ltd. Fujian Branch	17 districts in Fujian Province including Zhao'an, Hui'an, Xiapu and Fuding	Wind speed	Typhoon index insurance for mariculture
2020	China Life Property Insurance Co., Ltd. Fujian Branch; Fujian Fishery Mutual Insurance Association	Nanri Island and Pingtan Comprehensive Experimental Zone in Fujian	Red tide	Red tide index insurance for mariculture
2020	China Life Property Insurance Co., Ltd.	Weihai, Shandong.	Effective wave height	Effective wave height index insurance for oyster farming
2020	Co-insurance body composed of PICC Property and Casualty Co., Ltd. and China Ping An Property Insurance co., Ltd.	Huangyan District, Taizhou City, Zhejiang Province	Wind speed	Typhoon Index Comprehensive Insurance
2021	PICC Property and Casualty Co., Ltd. Jiangmen Branch	Jiangmen, Guangdong	Wind speed	Wind index insurance for oyster farming

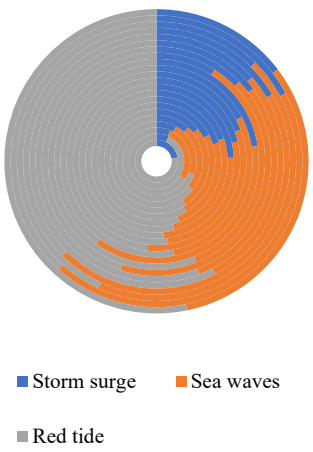
2015	PICC Property and Casualty Co., Ltd. Guangdong Branch; Ping An Property Insurance co., Ltd. Guangdong Branch	2015: 5 cities including Shantou, Shaoguan, Meizhou, Zhanjiang and Qingyuan; 2016: 5 cities were added including Shanwei, Maoming, Heyuan, Yunfu and Yangjiang; 2017: 4 cities were added including Huizhou, Zhaoqing, Chaozhou, Jieyang.	Typhoon and flood	Catastrophe Index Insurance
2021	PICC Property and Casualty Co., Ltd.	Weihai, Shandong	Wind speed	Wind index insurance for oyster farming
2021	China Ping An Property Insurance co., Ltd. Shanwei Branch	Shanwei, Guangdong	Wind speed	Policy-based wind index insurance for cage mariculture
2022	China Life Property Insurance Co., Ltd.	Weihai, Shandong	Seagrass bed carbon sink index	Ocean carbon index insurance
2022	China Ping An Property Insurance co., Ltd. Yangjiang Branch	Yangjiang, Guangdong	Wind speed	Wind index insurance for deep sea cage farming

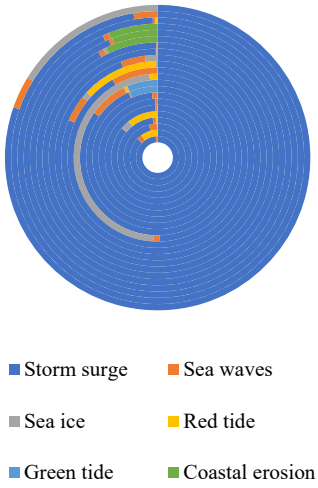
Source: Organized by authors.

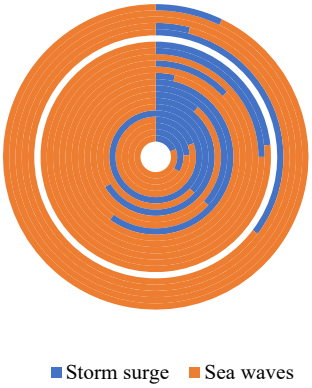
(2) The wind index is the most common underlying index for MDII products in China. This is in line with the occurrence of marine disasters attacking China. As shown in Fig 4 - Fig 6, storm surges are the most damaging type of marine disaster to which China is exposed, and most of the direct economic losses are caused by storm surges. Concurrently, red tides and waves occur more frequently and most deaths are caused by wave disasters. Recently, as the frequency and damage of marine disasters have grown, MDIIs have been introduced with various underlying marine disaster indexes, such as the red tide index and wave index. The design of the MDII product range has been progressively improved and become growingly diversified.

(3) MDII is expanding rapidly in China, however, it is mostly confined to local pilots. The main reason for this situation is that China has a vast sea area and there are significant environmental differences among these sea areas. Such limitation makes the index-based insurance subject to basis risks and systematic risks when it is signed by

various policyholders from different regions (Elabed et al., 2013; Mobarak and Rosenzweig, 2013; Jensen et al., 2016). As a result, this situation makes it difficult for insurance firms to operate homogeneous insurance policies on a large scale at the same time and for policyholders to be effectively protected.







Note: Inner loop → outer loop: 2000 → 2021.

Fig 4 Frequency of marine disasters

Fig 5 Direct economic losses resulting from marine disasters

Fig 6 Deaths (including missing) resulting from marine disasters

(4) The MDII is attracting an increasing number of commercial insurance firms. So far, the MDII insurers are mainly PICC Property and Casualty Co., Ltd., Taiping Property and Casualty Co., Ltd., China Life Property Insurance Co., Ltd., Ping An Property Insurance co., Ltd., etc. Generally, there are three categories of commercial insurance firms participating in the MDII pilots: First, the insurance firm underwrites the MDII independently. Second, several insurance firms underwrite the MDII together or set up a co-insurance body with other insurance firms as the insurer of MDII. For example, the typhoon Index Comprehensive Insurance launched in Huangyan, Zhejiang 2020 was underwritten by a co-insurance body composed of PICC Property and

Casualty Co., Ltd. and China Ping An Property Insurance co., Ltd. Third, the insurance firm cooperates with the fisheries mutual insurance association to underwrite the MDII, such as the weather index insurance for scallop farming in Laoting, Hebei, which is underwritten by China Fishery Mutual Insurance Association, Hebei Fishery Mutual Insurance Association, and An Hua Agricultural Insurance Co., Ltd. However, the insurers of MDII are still inadequate in number to service the market needs.

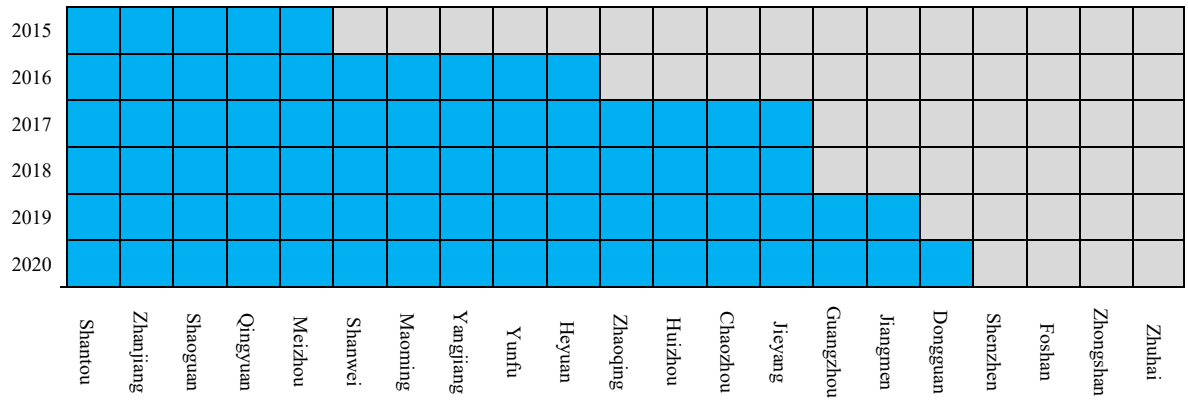
4 Challenges of China's marine disaster index insurance

Growing China's MDII pilots proves that China has been putting efforts into supplementing and upgrading the marine disaster risk management system. Yet, the pilots have also exposed the challenges to MDII in terms of coverage, demand, supply, and government subsidies.

4.1 Limited coverage of China's marine disaster index insurance

Only a portion of China's coastal regions is covered by MDII. There are MDII pilots launched in China's most coastal provinces. However, these pilots are generally available in small regions. Specifically, most of the pilots are launched in the sea or coastal areas where the mariculture activities are located, with less coverage for land areas. Thus far, the MDII has not yet achieved full coverage of all sea areas, nor does it cover all of China's coastal regions. For example, as the pioneer in developing catastrophe index insurance, Guangdong has been exploring pilots since 2015 with 5 cities including Shantou, Zhanjiang, Shaoguan, Qingyuan, and Meizhou. As shown in Fig 7, the cities engaged have grown consistently year by year. By 2020, 17 cities in Guangdong were covered by catastrophe index insurance, with a coverage ratio of

80.95%, whereas Guangdong has yet to obtain full coverage.



Note: The blue area represents the coverage area of catastrophe index insurance.

Fig 7 The coverage of catastrophe index insurance in Guangdong

MDII products are not available for all industries in China's coastal regions that may suffer losses from marine disasters. MDII now is targeted at mariculture and only serves a few large local mariculture farming operators, while other sectors such as the power sector (wind power), agriculture, industry, and the service sector remain uninsured. Although the comprehensive MDII entered the insurance market in 2020 when the typhoon comprehensive insurance was launched in Taizhou, Zhejiang, it only serves one city and the location coverage is still narrow.

As for the economy and population distribution, the coverage of MDII is also inadequate. As MDII mainly serves mariculture, it provides risk management for the stability of the mariculture industry, as well as the income of fishermen. However, the share of gross fishery product and fishery population does not represent a high proportion of the gross product and population of the coastal regions, which is evident that only a small part of the economy and population are covered by MDII in China's coastal regions. Specifically, as shown in Fig 8, Hainan has the greatest share of fishery products in its GDP among 11 of China's coastal regions, which is only 7.83%. And the

fishery population accounts for about 3.0% of its total population, with Guangxi having the highest share of the fishery population in the total population at 3.31%. Given that the mariculture industry is far from being fully covered by MDII, the economy coverage of MDII is less than 7.83%, and the population is less than 3.31%, respectively.

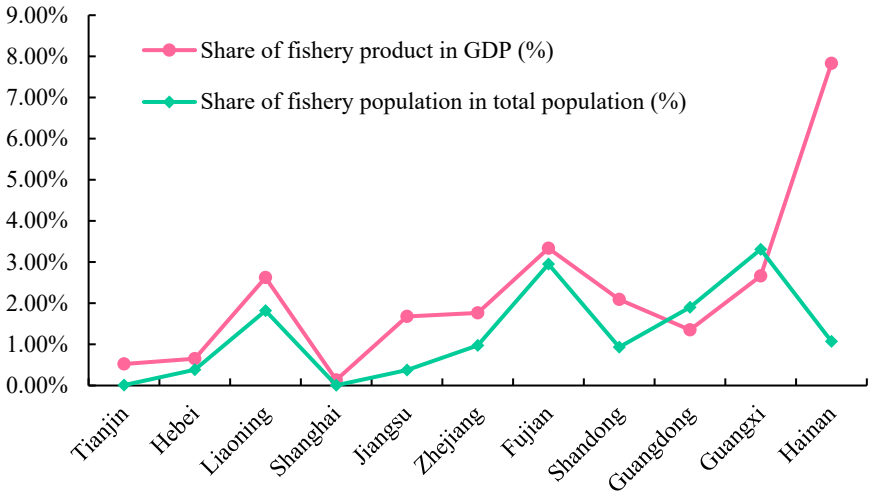


Fig 8 The coverage of China's marine disaster index insurance

Source: Calculated based on the China Fishery Statistical Yearbook.

4.2 Insufficient demand for China's marine disaster index insurance

China's coastal areas, which are frequently attacked by marine disasters, provide a huge potential market for MDII. The insured volume of MDII in pilots in recent years is summarized in Table 2. It appears that policyholders in MDII pilots in China are limited. The demand for MDII has not been fully released, which has resulted in an insufficient demand for MDII.

Table 2 Insured volume of MDII in China

Time	Pilot areas	MDII Products	The insured volume of MDII
2013	Liaoning	Wind index insurance for Zhangzidao Group	Only 1 policyholder of Zhangzidao Group.
2015	Liaoning	Weather index insurance for sea cucumber farming	Some farmers with the will to insure are uninsured, and some even know nothing about it. In 2018, only three households were insured by the two insurance companies without government subsidy policies.

2015	Shandong	Wind index insurance for seaweed, scallops, oysters and raft farming; Typhoon index insurance for abalone farming in Rongcheng; Wave height index insurance for offshore and deep sea net farming on Long Island	A total of 197 households (times) by May 2020.
2015	Guangxi	Wind index insurance for big oyster farming	Only 117 households were in the first round and 101 new households were added after the first claims.
2015	Hainan	Wind index insurance for deep-water net tank farming	Only 2 small-scale mariculture households.
2015	Hainan	Wind index insurance for rubber tree	6 private forest farms in Hainan.
2016	Hebei	Weather index insurance for scallop farming	Only 18 of the more than 300 farmers are insured.

Source: Organized by authors.

First, in the MDII pilots with limited coverage, the policyholders are mainly small-scale enterprises or mariculture operators, which results in a small insured volume of MDII. Meanwhile, there are still a large number of enterprises and households exposed to the risk of marine disasters who have not yet been approached by MDII. For example, only 2 small-scale mariculture households were insured for the wind index insurance for deep-water net tank farming piloted in Hainan in 2015. In Hebei, just 18 of more than 300 households covered by the weather index insurance for scallop farming chose to insure, with an insured ratio of 6%. Moreover, small-scale enterprises and mariculture operators in coastal regions are not the only ones who are vulnerable to marine disasters. Residents, farms, and enterprises in every industry in coastal regions also require compensation for losses caused by marine disasters, but they are not yet included as MDII policyholders.

Second, marine disaster vulnerable groups have not yet formed the awareness of using MDII to manage the risk of marine disasters. On the one hand, although the frequency of marine disasters has been increasing in recent years, their occurrences are still not as frequent as traffic accidents. Consequently, the public, which does not suffer

consecutive losses from marine disasters, tends to assume that marine disasters are unlikely to occur in their locations. Thus, the risks of marine disasters are often underestimated or ignored (Muis et al., 2016; Noy, 2016). On the other hand, MDII is not always triggered, which results in uncertain returns for policyholders in the short run. As the public is often less attentive to the probability of risk occurrence, shortsighted policyholders tend to focus more on the premiums they need to pay in the short run while ignoring the compensation function for marine disaster risks (Aert et al., 2018). In addition, policyholders who have been insured more than once but have not benefited may have the illusion of losing premiums, which leads the policyholders to be negatively reinforced for MDII (Huang et al., 2020; Liu et al., 2019; Jørgensen et al., 2020). At the same time, the uninsured will be positively reinforced and kept away from MDII. Through psychological restrictions, these reinforcing forces result in an insufficient demand for MDII (Stein, 2018).

Third, the demand for compensation for losses due to marine disaster risks is difficult to transform into the demand for MDII. On the one hand, those who are vulnerable to marine disasters have limited access to information about the risks of marine disasters and risk management means especially the emerging financial risk management tools (Ding et al., 2021). Thereby, they know little or nothing about index-based insurance and have not developed a clear understanding of MDII. On the other hand, in the existing MDII pilots, most of the MDII are designed and negotiated in a privately tailored way for each policyholder. Consequently, the poor communication between the public and insurance firms on supply and demand information about MDII

may result in the lack of demand constraints for insurance firms to innovate MDII based on collective choices. Thus, the marine disaster vulnerable groups often have no access to participate in MDII.

4.3 Inadequate supply of China's marine disaster index insurance

The supplier of MDII in China is insurance firms. Generally, China's MDIIs are designed by commercial insurance firms independently or jointly with research institutions and governments and operated after official approval by the authorities. Broadly, in these pilots, every insurance firm that underwrites MDII has experienced the issues of high claims and low profits (Raykov et al., 2015), which results in the situation that a sustainable supply of MDII is not supported by financial gains to fully cover the operations. Specifically, the inadequate supply of China's MDII can be reflected in the following three characteristics.

First, the loss ratio of MDII in China's pilots remains high, and cost control is challenging. As demonstrated in Table 3, the loss ratios of MDII in China's pilots in recent years have been extremely high, with some loss ratios over 100%. This phenomenon indicates that insurance firms have to pay large claims far over the premiums they received once the MDII is triggered. Such high loss ratios place high expectations on the insurance firm's claim capacity. On the other hand, as an emerging insurance product, MDII has a strong demand for professional actuaries and a database of high quality, and it is difficult and expensive to design. Moreover, the small volume of MDII makes it harder for insurance firms to obtain satisfying profits.

Table 3 The premiums and claims of MDII in China's pilots.

Time	Insurance firms	Pilot areas	MDII products	Premiums (million CNY)	Claims (million CNY)	Loss ratio (%)
2013	PICC Property and Casualty Co., Ltd.	Liaoning	Wind index insurance for Zhangzidao Group	20.0000	18.4950	92.5%
2015	Taiping Property and Casualty Co., Ltd. Shandong Branch	Shandong	Wind index insurance for seaweed, scallops, oysters and raft farming Typhoon index insurance for abalone farming in Rongcheng Wave height index insurance for offshore and deep sea net farming on Long Island	15.9387	26.3266	165.2%
2015	PICC Property and Casualty Co., Ltd.	Guangxi	Wind index insurance for big oyster farming	13.7399	11.5416	84%
2015	PICC Property and Casualty Co., Ltd. Hainan Branch	Hainan	Wind index insurance for rubber tree	0.7100	-	-
2016	China Fishery Mutual Insurance Association; Hebei Fishery Mutual Insurance Association; AnHua Agricultural Insurance Co., Ltd.	Hebei	Weather index insurance for scallop farming	2.7634	6.1300	221.8%
2017	China Life Property Insurance Co., Ltd. Fujian Branch	Fujian	Typhoon index insurance for mariculture	5.6328	17.4579	309.93%
2016 - 2017	PICC Property and Casualty Co., Ltd. Guangdong Branch; China Ping An Property Insurance co., Ltd. Guangdong Branch	Guangdong	Catastrophe Index Insurance	448.6400	518.6920	115.6%
2017 - 2020	Fujian Fishery Mutual Insurance Association; Commercial insurance firms	Fujian	Typhoon index insurance for mariculture	101.0000	36.93930	36.57%

Source: Organized by authors.

For example, the underwriters of Guangdong catastrophe index insurance, PICC Property & Casualty Co., Ltd., Ping An Property & Casualty Co., Ltd., Pacific Property & Casualty Co., Ltd., suffered a huge loss of CNY 282.8008 million after the catastrophe index insurance is triggered (Table 4). Consequently, insurance firms are inclined not to get involved in MDII to maintain sound operations and stable

profitability in the face of such huge losses.

Table 4 Profit of insurance firms after underwriting Guangdong catastrophe index insurance

	2016	2017
Total premium (million CNY)	262.9600	185.6800
Total claims (million CNY)	89.3460	429.3460
Loss ratio (%)	33.98%	231.23%
Total profit (million CNY)	37.8364	-282.8008
Profit ratio (%)	14.39%	-152.30%

Source: Organized by authors.

Besides, commercial insurance firms have not well taken on the supplier role of MDII independently yet. On the one hand, marine disaster risk, one of catastrophe risk, has characteristics of systemic risk. Once a marine disaster occurred, the insurers may have to pay multiple claims except for MDII, which needs to be backed by strong catastrophe reserves. However, to ensure their liquidity and maintain their profitability from the shock of the catastrophe insurance business, insurance firms are reluctant to put funds into their catastrophe reserves, which would fail to pay the compensation upon the occurrence of risks. Moreover, the younger insurance firms may not be able to establish adequate reserves. Even if they were willing to participate in MDII business, it would be difficult to fully claim their duty. On the other hand, marine disaster losses can hardly and strictly satisfy the law of large numbers (Ibragimov et al., 2015). Although insurance firms can redistribute the risks utilizing reinsurance, catastrophe bonds, and catastrophe options, their systematic and concomitant nature will keep these means from redistributing the risks effectively.

Furthermore, the absence of government subsidies undermines the willingness of insurance firms to get involved in MDII. Currently, the existing subsidy policies focus on the policyholders, and there is no subsidy policy support for insurance firms

designing and operating MDII in China. Without subsidies to relieve the financial constraints of insurance firms, they are held back by poor profits and huge claims and even forced to withdraw. For instance, the wind index insurance for Zhangzidao Group was terminated shortly after a claim of over CNY 80 million in 2016. Thus, it's really difficult for commercial insurance firms to supply and operate MDII sustainably without government subsidies.

4.4 Imperfect subsidy policies for China's marine disaster index insurance

China's MDII pilots proved that MDII has the characteristics of policy-oriented operations. China has issued a number of policies to guide the progress of MDII pilots. Subsidy schemes are an essential part of these policies, some of which have been implemented in the pilots. Table 5 outlines the subsidy scheme in China's MDII pilots recently. Indeed, subsidy schemes for MDII have been growing from the ground floor. However, there are differences in the subsidy policies, while the subsidy path is narrow.

Table 5 Subsidies for marine disaster index insurance products in China

Time	Pilot Regions	Products	Premium subsidy ratio			Proportion of premiums paid by policyholders
			Central government	Provincial government	City/county government	
2013	Liaoning	Wind index insurance for Zhangzidao group	-	-	-	100%
2015	Shandong	Wind index insurance for seaweed, scallops, oysters and raft farming Typhoon index insurance for abalone farming in Rongcheng Wave height index insurance for offshore and deep sea net farming on Long Island	-	-	-	100%
2015	Guangxi	Wind index insurance for big oyster farming	-	50%	20%	30%
2015	Hainan	Wind index insurance for rubber tree	-	90%		10%
2016	Hebei	Weather index insurance for scallop farming	-	70%		30%
2017	Zhejiang	Weather index insurance for seaweed farming	-	-	50%	50%

2017	Fujian	Typhoon index insurance for mariculture	-	20%	10%	70%
2019	Guangxi	Wind index insurance for oyster and peal shell farming	-	50%	10%	40%
2020	Fujian	Red tide index insurance for mariculture	-	40%	- -	60%
2020	Shandong	Effective wave height index insurance for oyster farming	-	-	- -	100%
2021	Guangdong	Wind index insurance for oyster farming	-	-	- -	100%
2021	Guangdong	Policy-based wind index insurance for cage mariculture	-	-	60%	40%
2020	Fujian	Typhoon index insurance for mariculture	-	20%	10%	70%
2020	Weihai, Shandong.	Effective wave height index insurance for oyster farming	-	-	50%	50%

Source: Organized by authors.

In terms of the targets of subsidy, the policyholders on the demand side of MDII are the target of most subsidies, while the insurance firms on the supply side of MDII are in urgent need of subsidy. Besides, all of the subsidy schemes for MDII in China are premium subsidies, whereby the government and the policyholders share the premium. Even so, only poor policyholders were able to be subsidized in some pilots. The limited coverage of premium subsidies has not worked as expected in motivating the demand for MDIIs. For example, in the pilot of mariculture index insurance launched in Liaoning in 2018, only three commercial insurance firms operated the insurance policies, of which only three householders signed the insurance policies with the two firms that were not covered by a premium subsidy from the government. On the other hand, the absence of subsidy on the supply side exacerbates the dilemma that commercial insurance firms operate MDII policies with poor profits.

As for the source of subsidies, the subsidy for MDII in China is mostly sponsored by the provincial government, municipal government, and county government, and few

of them are granted by the central government. Besides, the proportion of premiums covered by subsidy varies from pilot to pilot and that specific subsidy scheme that can satisfy the progress of MDII remains insufficient. Moreover, some MDII pilots have not yet received any subsidies, while some MDII pilots have been listed in the agricultural insurance catalogue and subsidized as such. However, the traditional agricultural insurance subsidy plan may be not suitable for MDII as they are not at the same development stage. MDII in China is in its early stage where both its demand and supply are insufficient, while the well-developed traditional agricultural insurance subsidy scheme may not achieve the expected effect in promoting MDII. Consequently, the situation of no subsidy or non-suitable subsidy not only makes it difficult to achieve the purpose of promoting the progress of MDII, but also wastes resources.

5 Potential policy responses of China's marine disaster index insurance

Coastal areas are hosting the most active production and economic activities. Yet, the risks caused by frequent and various marine disasters have led to a continuous deterioration of the ocean and coastal environment and the security of people's livelihoods, which seriously threaten the sustainable development of the blue economy. MDII, as an emerging risk management tool, is an essential safeguard to strengthen resilience and improve the vulnerability of coastal areas to marine disasters, facilitating sustainable ocean and coastal management. Nevertheless, MDII is caught in a dilemma of insufficient supply and demand with multiple challenges as analyzed above. Thereby, we propose potential policy responses and management implications for improving the operation of MDII in China with the concern to support sustainable ocean and coastal

management.

5.1 Improving the market ecosystem and regulatory system for MDII

Multiple pilots around the world have proved that policy index-based insurance is an ideal model for compensating losses caused by marine disasters, acting a good role in improving the vulnerability of coastal areas to marine disasters (Cohen et al., 2002; Zheng et al., 2021). The incomplete ecosystem of the marine disaster insurance market requires government action (Charpentier and Le, 2014). The government should design a scientific development plan for MDII that covers most of the marine disasters that may attack China's coastal regions, including storm surges, sea ice, red tide, coastal erosion, etc. Also, the government should accelerate the special legislation on marine disaster insurance, especially to make detailed provisions on the content of MDII, through which to clear the rights, obligations, and business contents of relevant subjects in MDII. Meanwhile, relevant instructions should be provided to coordinate the formulation and implementation of this special legislation with other laws and regulations. Considering that MDII is a quasi-public product (Zheng et al., 2020), and drawing on the experience of catastrophe insurance in Japan, America, and France (Xia et al., 2017; Zheng et al., 2020), the MDII could be conducted with the moderate compulsory requirement. Meanwhile, it is recommended that the government introduce third-party to integrate the advantages of various insurance firms of various natures in terms of expertise, and service channels (Alam et al., 2020). Accordingly, a moderately competitive ecosystem for MDII will be established to ensure the stable functioning of MDII business.

5.2 Enhancing the capability of MDII insurers to deal with instant massive claims

The sound-running insurance firms are the cornerstone of the sustainable supply of MDII, while the sustainability can be easily torn down by the instant massive claims of MDII. Accordingly, it is critical to provide insurance firms with adequate methods to relieve the pressures of MDIIs' claims and improve their capability to deal with instant massive claims (Surminski et al.,2016). Catastrophe bonds and catastrophe funds are good means to facilitate the pressures of massive MDII claims to be transferred and distributed to the financial markets. Thus, it is recommended to accelerate the establishment of a marine disaster compensation fund. Subsequently, a tiered claims mechanism can be put in place whereby the insurer, the reinsurer, and the fund share the responsibility for MDII claims. Specifically, claims that exceed the underwriting capacity of the insurer and reinsurers should be undertaken by the fund. Meanwhile, marine disaster bonds can also play the role of channelling the financial market and insurance market. Especially, marine disaster bonds with index triggering conditions can be directly matched to MDII, which enables the marine disaster risks mitigated cross-market, cross-time and cross-region. Given that there are not many MDIIs launched in China, and the marine disaster compensation funds and bonds have not been set up yet, the government has to take the responsibility for ensuring that insurance firms design and operate MDII business. International experiences show that government intervention is a smart way to address index insurance market failures, where the government should establish public-private partnerships with insurance firms to develop appropriate insurance products to maintain the operation of the insurance

market (Cohen et al., 2002; Alam et al., 2020). For example, providing subsidies or emergency plans to these insurance firms that are on the verge of bankruptcy due to the massive claims when MDII is triggered.

5.3 Diversifying the channels and forms of subsidy policies for MDII

Motivated by the goal of sustainable development, achieving sustainable ocean and coastal management in coastal regions has become the common guidance of marine policy. It is a harsh challenge to avoid the excessive losses caused by frequent marine disasters. MDII offers a sound approach to tackling it, which needs the strong support of government subsidies. One way to solve the problem is to diversify the channels and forms of subsidy policies for MDII (Coble et al., 1997; Zhang et al., 2020). Specifically, the government should subsidize the insurance firms/co-insurers of MDII while subsidizing the policyholders. Particularly, the government subsidy scheme needs to be expanded from the single-channel used now to a dual-channel through which the government subsidies can be allocated to both the demand and supply sides. Moreover, the form of government subsidies also needs to be enriched. The government could provide financial support to insurance firms through financial allocations for the design and operation of MDII. Also, tax incentives can be used to reduce the tax burden on insurance firms and policyholders (Tuo and Zhu, 2007). Besides, we recommend the preferential financing scheme of "MDII+Loan interest subsidy" to provide support for these insurance firms and policyholders who are participating in MDII with financial constraints. In addition, the government subsidies should be dynamically modified to fit the local demands for marine disasters risk management, as well as the spatial

distribution of marine disaster risks, and coastal regions' vulnerability to marine disasters (Grey et al., 2004; Knight et al., 2010; Hazell and Varangis, 2020). Broadly, through the diversified subsidy channels and forms, the cost of participating in MDII will be reduced significantly, thereby the demand from the potential victims in coastal regions can be improved.

5.4 Promoting the public's awareness of using MDII to manage marine disaster risks

The public's perception of marine disaster risks is one of the most important motivations for developing MDII (Sherrick et al., 2004). Given that China's marine disaster risk management relies too much on the government's post-disaster aid and the public lack of understanding of marine disaster risk management, the government should take measures to improve public awareness of using MDII to manage marine disaster risks. The first and foremost condition to address the challenge is to establish a reliable source of marine disaster risk information. Insurance firms or research institutes should assess marine disaster risks on time, and issue reports publicly by which timely and accurate information about marine disaster risks can be provided to the public. On the other hand, public access to information about marine disaster risk and MDII also needs to be broadened. Using big data and information technologies, especially the widely used social media, marine disaster risk information can be widely delivered to the public in the form of short videos, tweets and audiobooks, etc. In particular, the residents or enterprises in coastal regions that are vulnerable to marine disasters should be accurately targeted with information on MDII and marine disaster risks, leading the public to form an awareness of using MDII to manage their exposure to marine disasters.

5.5 Designing scientific MDII products

Scientific MDII products are the backbone of its role in improving the risk reduction caused by marine disasters and supporting sustainable development in coastal areas. The design of MDII products is a complex process involving numerous factors of environmental, economic, social, resource, and cultural elements (Hisamatsu et al., 2020; Li et al., 2020). Moreover, a scientific MDII product cannot be designed successfully without precise actuarial techniques and a complete marine disaster database that contains long-term historical data on the physical characteristics of marine disasters and the vulnerability of the coastal regions (Afriyie-Kraft et al., 2020). The shortage of database and actuarial talents makes it necessary for the government to improve the conditions for designing scientific MDII products. Thereby, it is recommended to establish a standardized marine disaster database with a sharing platform for information exchange and use by insurance firms. This database should be built in conjunction with the MDII product design requirements, integrating data information on storm surges, red tide, sea ice, waves, and other major marine disaster risks and losses. At the same time, it is also recommended to build platforms for innovation and transformation of disaster insurance science and technology by combining industry, academics and research, through which to gather and train interdisciplinary and international actuarial talents in MDII. The growing pool of talents and data enables insurance firms to design scientific MDII products, thereby promoting a prosperous MDII market in China.

6 Conclusion

Robust marine disaster risk reduction plans are one of the essential supports for sustainable ocean and coastal management, in which MDII plays a crucial role as an emerging insurance product. Drawing on the concerns of improving sustainable ocean and coastal management, this paper tracks the evolution history and reviews the pilots of China's marine disaster index insurance. By examining the MDII products and the subsidy policies in these pilots, we analyze the challenges that China's MDII are facing. Targeting these challenges, we proposed potential policy and management implications to promote the evolution of MDII in China, thereby facilitating the sustainable development and conservation of oceans and coasts.

China has been piloting MDII since the wind index insurance for Zhangzidao Group was launched in Dalian in 2013. In the last decade, China has made great progress in promoting MDII, but it is still struggling with insufficient supply and demand, and facing many operational challenges. Given the spatial distribution of the MDII pilots in China, MDII covers limited location areas and involves few industries. No more than 7.83% of the GDP and 3.5% of the population are protected by MDII in coastal regions in China. On the demand side, policyholders in the limited pilot areas are mostly small-scale householders, resulting in an insufficient demand for MDII. This happens because the public lacks an understanding of marine disaster risks and MDII, resulting in limited awareness of using MDII to manage potential marine disaster risks. On the supply side, the heavy claims and cost of MDII leave the insurance firms with little profits to sustain their operations, resulting in the inadequate supply of MDII. As one of the policy-oriented emerging insurance, most of the MDII pilots are supported

by policies. Yet, the existing subsidies are all subsidies for policyholders with the proportions of premium subsidy varying in each pilot, neglecting the insurers on the supply side. Moreover, there is no central subsidy for MDII, nor is there a specific subsidy program that could fit the needs of MDII development. These challenges have limited the MDII in China from successfully performing its function of improving the ability to reduce marine disaster risks in facilitating sustainable ocean and coastal management.

To overcome these challenges and improve the marine disasters risk reduction in coastal areas, we propose some possible solutions, formulating long-term plans for MDII, which include improving the market ecosystem and regulatory system for MDII, enhancing the capability of MDII insurers to deal with instant massive claims, diversifying the channels and forms of subsidy policies for MDII, promoting public awareness of using MDII to manage marine disaster risks, and designing scientific MDII products. These solutions aim to profoundly activate the vitality of China's MDII market and improve its efficiency, so as to close the gap in the risk management system for marine disasters as much as possible.

This study has the following limitations, as well as some opportunities for future studies. The potential policy recommendation suggests that governments should provide appropriate subsidy schemes for MDII. However, the reasonable level and scale of the subsidy remain unclear. Future work on estimating the reasonable subsidy for MDII is needed. In addition, the index-based claim scheme of MDII allows it to serve the policyholders as insurance and financial derivatives. In future, the dual functions

MDII can be considered jointly in the operation framework of MDII, enabling MDII to play its role in serving the sustainable development of coastal regions better.

Declaration of competing interest

The authors declare no conflict of interest.

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