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Marine environmental regulation and green technology innovation: evidence from enterprises in coastal areas of China

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It is of great significance to explore the effect of marine environmental policies to promote the sustainable development of the marine economy. This article takes the 'National Marine Ecological Civilization Demoznstration Zone' (hereinafter referred to as the 'Demonstration Zone') as a quasi-natural experiment and adopts the difference-in-difference method to explore the effects of marine environmental regulation on green technology innovation of micro-enterprises in coastal areas and on the high-quality development of the regional economy. This article finds that marine environmental regulation can promote the green technology innovation of enterprises in coastal areas. The mechanism analyses show that marine environmental regulation increases the government's attention to the environment and promotes industrial structure upgrading, thus positively affecting local enterprises' green technology innovation. Cross-sectional analyses show that the increase in green technology innovation is more pronounced in resource-based cities, areas with high marine economic dependence and high green finance development, as well as in enterprises with low financial constraints and marine-related enterprises. Additionally, marine environmental regulation significantly increases green invention patents and independent green innovation by enterprises in coastal areas. At the macro level, we find that the impact of marine environmental regulation on green technology innovation ultimately leads to high-quality development of the local economy. Based on the above results, this article suggests that the government should actively explore and practice the construction of marine environmental ecological civilization, and further improve marine environmental regulation to encourage firms to carry out green technological innovation activities.

KEYWORDS

marine environmental regulation, green technology innovation, coastal areas, China, economic and environmental effects

1 Introduction

In the context of increasingly severe environmental and resource problems, countries have begun to put green and sustainable development in an important position. At present, green technology innovation has green and innovative characteristics, and it is becoming a key driving force for transforming economic development mode and high-quality development and an important support for coordinating pollution prevention and control, climate change and economic development (Chen and Lee, 2020). As the main body of green technology innovation, the green technology innovation performance of enterprises has an important impact on the sustainable development of the ecological environment and the high-quality development of the economy. From the perspective of China's green technology innovation trend, China's integration of green technology in products and production methods has become an important direction for the development of environmentally sensitive enterprises. However, the negative externalities of environmental pollution and the positive externalities of innovation activities make enterprises reluctant to participate in green technology innovation activities (Rennings, 2000). In this case, how to internalize the double externalities into the enterprise decision-making becomes the key to improving enterprise green technology innovation.

Environmental regulation refers to the government's direct and indirect intervention in environmental pollution to control the pollution level and improve the ecological environment, and it is an important means and tool to encourage enterprises to take environmental protection actions (Rugman and Verbeke, 1998). Whether environmental regulation can drive innovation and enhance the competitiveness of enterprises has always been a hot research topic in innovation, but no consensus has been reached on the research conclusions. The traditional school of neoclassical, based on a static perspective, believes that environmental regulations increase the production cost of enterprises, squeeze out domestic and foreign market resources (Gollop and Roberts, 1983), restrict economic development and hinder technological innovation (Gollop and Roberts, 1983). The Porter hypothesis advocates active environmental protection policies. It holds that strict and appropriate environmental protection policies can stimulate enterprises to carry out technological innovation, and the innovation benefits can offset or even exceed the environmental protection costs, thus ensuring or improving the competitiveness of enterprises (Porter and van der Linde, 1995).

Marine environmental protection is an important part of global sustainable development. Enterprises in coastal areas, as major players in marine economic activities, can help reduce the negative impact on the marine ecological environment by controlling resource consumption, the discharge of wastewater, waste and solid pollutants (Islam and Tanaka, 2004; Ghisellini et al., 2016). Their technological innovation in environmental protection will also have a significant impact on improving the quality of the marine environment (Frondel et al., 2008; Hering et al., 2013; Golden et al., 2017). Enterprises in coastal areas need to bear the social responsibility of marine environmental protection, and the corresponding environmental regulation means are indispensable. Existing studies on the ecological effects of marine environmental regulation have revealed the significant effects of near-shore marine regulation and industrial structure optimization on environmental improvement (Zhang et al., 2021). However, relevant studies have also pointed out the limitations of coastal environmental regulation, arguing that increasing investment in micro-individual environmental behaviour is more effective in reducing garbage along coastal zones than policy investment (Willis et al., 2018). This paper studies the relationship between marine environmental regulation and the green technology innovation behaviour of micro-individuals in coastal areas and further explores its economic and environmental effects on the region, which will provide a new perspective for the ecological and economic effects of marine environmental regulation.

In 2012, the State Oceanic Administration of China issued the Interim Measures for the Administration of the Construction of Marine Ecological Civilization Demonstration Zones and the Index System for the Construction of Marine Ecological Civilization Demonstration Zones (Trial Implementation) (Ministry of Natural Resources of the People's Republic of China, 2012) to ensure a healthy marine ecosystem by piloting demonstration zones, guided by ecological and environmental protection. Emphasizing the governance orientation of market-oriented allocation, fine management and paid use, vigorously promoting the construction of marine ecological civilization in coastal areas, guiding coastal areas to correctly handle the relationship between economic development and marine ecological environmental protection, and stably supporting the sustainable development of China's economy. The document issued by the State Oceanic Administration of China defines four main tasks for the construction of demonstration zones: optimizing the industrial structure in coastal areas and transforming production methods, strengthening the control of pollutant discharge into the sea to improve the quality of the marine environment, strengthening marine ecological protection and construction and maintaining marine ecological security, and fostering awareness of marine ecological civilization and establishing a concept of marine ecological civilization. In 2013 and 2015, China set up demonstration zones in two batches, covering 24 cities and counties (districts), providing a favourable research scenario for marine environmental regulation to drive green technology innovation of enterprises in coastal areas.

This paper takes the 'National Marine Ecological Civilization Demonstration Zones' (hereinafter referred to as 'demonstration zones') established in 2013 and 2015 as a quasi-natural experiment scenario and uses the data of listed companies in provincial and coastal areas of China from 2008 to 2020. The effects of marine environmental regulation on green technology innovation of micro-enterprises in coastal areas and on macro-economic growth and environmental improvement were investigated by the multi-point DID method. We find that in coastal areas, compared with enterprises in non-demonstration areas, enterprises located in demonstration areas have significantly increased their green technology innovation activities, and this conclusion is still valid after a series of robustness tests. Furthermore, the impact of marine environmental regulation on enterprises' green technology innovation is more significant in resource-based cities, areas with high marine economic dependence and high green finance development, as well as in enterprises with low financial constraints and marine-related enterprises. Under the requirements of marine environmental regulations, the quality of green patents of enterprises in coastal areas significantly improves, which is reflected in the significant increase in the number of green invention patents. As for the choice of innovation mode, marine environmental regulation leads to an increase in the number of independent innovations of enterprises in coastal areas, indicating that enterprises pay more attention to internal R&D investment rather than to cooperating with others. Finally, we find that the positive impact of marine environmental regulation on green technology innovation can significantly increase regional GDP, and significantly reduce energy consumption, indicating that the positive impact of green technology innovation on enterprises can promote high-quality economic development in coastal areas.

The marginal contribution of this paper is mainly reflected in the following three aspects. First, this study provides a new research perspective for the study of the ecological effects of marine environmental regulation. Studies on the ecological effects of marine environmental regulation mostly focus on the theoretical connotation and index system evaluation, and the environmental effects of demonstration zones are mostly tested from the provincial level in data analysis (Den Hartog, 2021; Lin et al., 2022, 2023). The environmental and economic effects of marine environmental regulation are rarely explored from the perspective of enterprise green technology innovation at the micro level. Based on the quasi-natural experiment scene of demonstration zone construction, this paper explores the impact of marine environmental regulation on the green technology innovation of micro-individuals in coastal areas, provides empirical evidence for the effect of marine environmental regulation and supplements the existing studies on marine environmental regulation.

Second, this study reveals the driving factors for enterprises in coastal areas to actively carry out green innovation activities, expands the theoretical extension of Porter's hypothesis and provides China's micro evidence for the debate on whether environmental regulation and enterprise competitiveness are 'conflicting' or 'coordinated' (Rugman and Verbeke, 1998). At present, relatively little research has been made on how enterprises in coastal areas should bear the responsibility of marine environmental protection in the process of developing themselves. Studies on the economic consequences of environmental regulations remain controversial, and most of them focus on factors at the national and regional levels. Few studies have investigated how micro-enterprises in China respond to environmental regulations, especially the lack of targeted studies on enterprises in coastal areas. Through the study of marine environmental regulation driving green technology innovation of enterprises in coastal areas, this paper provides empirical evidence for the study of the innovation behaviour of enterprises in coastal areas and the economic consequences of environmental regulation.

Third, in terms of research paradigm, this study reflects micro-enterprise behaviour on the quality of macroeconomic development, enriching the research framework of the interaction between macro-economic policy and micro-enterprise behaviour. Existing studies have extensively discussed how macro-environmental economic policies affect micro-enterprises green technology innovation, but few studies have explored the feedback effect of micro-enterprises behaviours on macro-policies (Carrión-Flores et al., 2013; Chhaochharia et al., 2019). In this paper, micro-enterprise green technology innovation is linked with macro-economic high-quality development, which not only deepens the understanding of the economic consequences of enterprises' green technology innovation behaviour in coastal areas but also provides a micro-enterprise-level explanation for the 'double dividend' of economic growth and environmental improvements achieved by marine environmental regulation.

The rest of this article is as follows. The second part is the literature review and research hypotheses. The third part is the research design, including research methods, data sources and model design. The fourth part is the result analyses. The fifth part is further analyses. The final part is the main conclusions and discussion.

2 Literature review and research hypotheses

2.1 Literature review

The implementation of a marine environmental policy not only has a direct impact on the marine ecological environment but also has a wide impact on economic activities. Existing studies on the effects of marine policies mainly focus on ecological effects and economic effects. The research on the ecological effects of environmental policies in the academic circle mainly focuses on the construction of marine protected areas (MPAs) and the related policies of marine environmental pollution protection and control. MPAs are one of the most common and effective ways of regulating the marine environment. Edgar et al. (2014) explored the conservation effects of MPAs. They found that MPAs with large areas, fishing bans, strong law enforcement and long construction times had the best ecological results. These characteristics are known as NEOLI (no-take, enforced, old, large, isolated) characteristics. MPAs with these characteristics are significantly better than other areas in terms of fish numbers, the proportion of large fish and shark numbers. Gill et al. (2017) studied 964 MPAs worldwide and found that the implementation of MPAs can improve fish biomass. Among the relevant studies on marine environmental pollution, Jambeck et al. (2015) focused on plastic pollution. They estimate that between 4.8 and 12.7 million tonnes of plastic waste entered the oceans in 2010. Research shows that implementing plastic waste management policies can significantly reduce the amount of plastic pollutants entering the ocean. Chen et al. (2018) studied the water quality of China's offshore waters and found that the implementation of strict pollutant discharge standards and regulatory measures can effectively improve the water quality of offshore waters. They analysed water quality data from China's offshore waters between 1978 and 2016 and found that offshore water quality has improved significantly since stricter water pollution prevention policies were implemented in 2001. Willis et al. (2018) found the limitations of shoreline environmental protection policies and pointed out that increasing investment in individual environmental protection behaviours is more effective than policy investment in reducing garbage along coastal zones.

The studies on the economic effects of marine environmental policies have not reached a unified view. Sala et al. (2013) found that MPAs reduced fish catch in the short term and significantly increased fishery output and income after a longer period. In their study, they simulated a scenario in which 30% of the world's oceans were set aside as completely protected areas and found that catches would fall by 15% in the short term but increase by more than 30% in the long term. The study highlights the long-term economic benefits of marine environmental policies. Costello et al. (2016) pointed out that scientific fishery management can not only restore fish stocks but also significantly improve the economic benefits of fisheries.

However, marine environmental policies can also have negative economic impacts, especially for communities that depend on fisheries. Bennett and Dearden (2014) studied MPAs in Thailand and found that the establishment of such areas had an impact on the employment of local fisherfolk. Barbier (2017) pointed out that the economic effects of marine environmental policies are often long-term and indirect, which is difficult to quantify accurately. For example, the conservation of marine biodiversity may provide valuable resources for future biotechnology development, but this potential value is difficult to realise in the short term.

Porter's hypothesis is the most representative theory on the relationship between environmental regulation and innovation. Porter and van der Linde (1995) proposed that properly designed environmental regulations can stimulate enterprise innovation, improve resource utilization efficiency, offset or even exceed environmental compliance costs and ultimately enhance enterprise competitiveness. This hypothesis provides a theoretical basis for a large number of subsequent empirical studies. Porter's hypothesis has been supported by some studies on marine environmental regulation. Some scholars discussed the impact of marine environmental regulation on enterprise innovation from the perspective of innovation compensation. The increased costs caused by marine environmental regulation are believed to stimulate firms to find solutions through innovative activities to offset the regulatory costs (Makkonen and Repka, 2016). Few studies have been done on marine environmental regulation and green technology innovation. Horbach et al. (2012) studied the marine environmental policy of the European Union and found that setting strict pollutant discharge standards could promote an increase in the number of patent applications related to ship-clean technology. Cainelli et al. (2012) studied the marine environment in Italy and found that stricter water quality standards were positively correlated with the number of environmental patents of local enterprises. However, the impact of marine environmental regulations on patent applications may have a lagging effect Marin and Lotti (2016), found that the impact of the implementation of ship emission control areas (ECA) on relevant green patents was significant only two to three years after the implementation of the policy.

On the whole, the ecological and economic effects of marine environmental policies have been fully studied, and the importance and necessity of implementing marine environmental policies have been revealed. The research on the relationship between marine environmental regulation and technological progress provides a rich theoretical basis and empirical support for this paper to explore marine environmental regulation and green technology innovation of enterprises in coastal areas. However, due to the research on the ecological effects of marine environmental regulations, the environmental effects of demonstration zones are often tested at the provincial level (Den Hartog, 2021; Lin et al., 2022, 2023). The environmental and economic effects of marine environmental regulations are rarely explored from the perspective of enterprise green technology innovation at the micro level, and relatively little research has been done on how enterprises in coastal areas should bear the responsibility of marine environmental protection in the process of developing themselves. Studies on the economic consequences of environmental regulations are still controversial, and most of them focus on factors at the national and regional levels. Few studies have investigated how micro-enterprises in China respond to environmental regulations, especially the lack of targeted studies on enterprises in coastal areas, which cannot easily meet the needs of the sustainable development of the marine environment in the new situation. Taking the demonstration zones established in 2013 and 2015 as quasi-natural experiment scenes, this paper adopts the multi-point DID method to investigate the impact of marine environmental regulations on the green technology innovation of micro-enterprises in coastal areas and their effects on macroeconomic growth and environmental improvement, compensating for the shortcomings of existing studies.

2.2 Research hypotheses

Under the theory of new institutional economics, environmental regulation, as a formal institutional arrangement, will affect the innovation behaviour of enterprises (North, 1990). Porter's hypothesis proposes that reasonably designed environmental regulations can stimulate enterprise innovation and improve resource utilization efficiency, thus achieving a win-win situation for environmental protection and economic development (Porter and van der Linde, 1995).

The guiding principle for the construction of marine ecological civilization demonstration zones is to adhere to the concept of ecological civilization, guide coastal areas to correctly deal with the relationship between economic development and marine ecological environmental protection, and promote the shift in the mode of development of coastal areas and the construction of marine ecological civilization. Therefore, we believe that the construction of marine ecological civilisation demonstration zones will have a significant impact on the local government's marine ecological environmental protection governance and the need for optimising and upgrading the industrial structure.

On the one hand, the construction of marine ecological civilisation demonstration zones increases the attention of local governments to marine ecological environmental protection and governance. Local governments that have been approved as national marine ecological civilisation construction demonstration zones highly value the 'golden signboard' of the demonstration zones. They have the incentive to be more proactive in their environmental governance behaviour around their marine ecological endowments, and to strive for synergy between economic development and the protection of marine ecosystems. On the other hand, the construction of marine ecological civilisation demonstration zones needs to promote the shift in the development mode of coastal areas. Industrial structures play a crucial role in the effectiveness of regional environmental governance (Du et al., 2021). Prior to the granting of the national marine ecological civilisation construction demonstration zone, local governments preferred the crude development model and vigorously developed heavy industries out of the consideration of promoting local economic growth, which could obviously boost economic growth but was often accompanied by the aggravation of environmental pollution (Lin et al., 2024) After being granted a national-level marine ecological civilisation construction demonstration zone, accelerating the optimisation and upgrading of the industrial structure has become an important way of environmental governance for the purpose of promoting the synergy between local economic growth and marine ecological environmental protection. In this context, increased government attention to ecological environmental protection and increased need for industrial structure optimisation and upgrading shift cost-benefit trade-offs of enterprises' green investment decisions and provide incentives for firms to enhance green technology innovation.

From the cost perspective, when marine environmental regulations are strengthened, enterprises in coastal areas need to invest more resources in pollution control, thus increasing their environmental compliance costs (Ambec et al., 2013). Under such cost pressure, enterprises reduce environmental pollution in the short term by means of 'end treatment' such as production reduction, production suspension or investment in pollution control, potentially also increasing the operating costs of enterprises (Clarkson et al., 2004) and harm normal production and business activities of enterprises (Gray and Shadbegian, 1993). At this time, enterprises urgently need to seek innovative solutions to meet environmental requirements and reduce costs (Kesidou and Demirel, 2012). Green technology innovation is an important way to reduce pollutant emission and environmental governance costs (Porter and van der Linde, 1995; Frondel et al., 2008; Testa et al., 2011), therefore, increasing R&D investment and developing environment-friendly technologies have become the choice for enterprises to cope with cost pressure.

From the benefit perspective, enterprises in coastal areas have many advantages in adopting green technology innovation to achieve energy conservation, emission reduction and efficient utilization of resources. Firstly, When Marine environmental regulations are strengthened, green technology innovation not only has long-term energy-saving and emission reduction effects but also helps enterprises to form cost advantages (Christmann, 2000) and product differentiation advantages (Porter and van der Linde, 1995), and can also win 'green reputation' for enterprises (Tang et al., 2018), enabling enterprises to obtain environmental and economic benefits (Hart, 1995). And, compared with the introduction of environmental protection equipment or outsourcing investment in environmental protection transformation, which is difficult to be known by the outside world, the green patent application is not only a successful signalling mechanism but also a transaction realization mechanism. Enterprises in coastal areas externalize their internal 'green transformation' consciousness into active environmental protection measures through open, visible and costly imitation of green patent applications and communicate their environmental stance through market and information intermediaries such as analysts and institutional investors to make stakeholders such as potential customers and investors more willing to deal with them (Huang and Li, 2017; Bardos et al., 2020; Fang and Na, 2020).

From the incentives perspective, the strengthening of marine environmental regulations has put forward higher requirements for the environmental management capabilities of enterprises in coastal areas (Darnall and Edwards Jr., 2006), and enterprises with environmental technology advantages will gain more market share (Hart and Dowell, 2011). However, enterprises with poor environmental performance face survival challenges (Testa et al., 2011). To gain competitive advantages and development opportunities, enterprises have a stronger incentive to increase investment in green technology innovation (Chen et al., 2006), build technical barriers (Lanoie et al., 2011), and gain market recognition through green innovation products, improve enterprise economic performance ((Ghisetti and Rennings, 2014). Berrone et al. (2013) adopted the data of 326 listed companies from polluting industries in the United States and found that when enterprises face greater government regulatory pressure and NGO regulatory pressure, heavily polluting enterprises will respond to the institutional pressure through more active green innovation. Kong et al. (2020) based on empirical evidence from 198 Chinese manufacturing enterprises, showed that under the pressure of external stakeholders and strict resource constraints, green technology innovation is an effective strategy for enterprises to deal with environmental governance issues. All this evidence shows that green technology innovation is a common means for enterprises to cope with environmental regulations. In other words, enterprises hope to improve evaluation from stakeholders through green technology innovation, promoting enterprises to form competitive advantages and win investment value. These benefits will attract enterprises to independently and continuously carry out green technology innovation.

To sum up, this paper puts forward the following hypothesis:

Hypothesis 1: Marine environmental regulation will promote green technology innovation of enterprises in coastal areas.

3 Research design

3.1 Sample selection and data sources

Under the requirements of sustainable development, the national ministries and commissions and provinces, municipalities directly under the central government and autonomous regions have strengthened the organization and guidance of ecological civilization construction. In February 2013, with the approval of the State Council, 12 cities (counties and districts) in the four pilot provinces of marine economic development in Shandong, Zhejiang, Fujian and Guangdong were identified as the first batch of demonstration zones by the State Oceanic Administration. Weihai, Rizhao and Changdao counties in Shandong Province; Xiangshan, Yuhuan and Dongtou counties in Zhejiang Province; Xiamen, Jinjiang and Dongshan counties in Fujian Province and Hengqin New Area and Nanao and Xuwen counties in Zhuhai, Guangdong Province, were the first national-level demonstration zones. In December 2015, to further promote the construction of marine ecological civilization, the State Oceanic Administration announced the second batch of demonstration zones, which totalled 12: Panjin City and Lushunkou District of Dalian City in Liaoning province, Qingdao City and Yantai City in Shandong province, Nantong City and Dongtai City in Jiangsu province, Shengsi County in Zhejiang province, Huizhou City in Guangdong province and Dapeng New District in Shenzhen City, Beihai City in Guangxi Zhuang Autonomous Region, Sanya City and Sansha City in Hainan Province. The four main tasks of creating the demonstration zone are optimizing the industrial structure of the coastal areas and changing the development mode, strengthening the control of pollutant discharge into the sea to improve the quality of the marine environment, strengthening marine ecological protection and construction and maintaining marine ecological security, fostering awareness of marine ecological civilization and establishing a concept of marine ecological civilization. China should adhere to the concept of ecological civilization and guide coastal areas to correctly deal with the relationship between economic development and marine ecological environment protection, the 'Opinions on the Construction of the Marine Ecological Civilization Demonstration Zone' said.

Based on this background, in the process of examining how marine environmental regulations marked by the approval of demonstration zones affect the green technology innovation strategy of micro-enterprises, this paper focuses on the quasi-natural experiment of demonstration zones approved by the State Oceanic Administration of China in 2013 and 2015. A-share listed companies in Shanghai and Shenzhen stock markets in China's coastal areas from 2008 to 2020 are selected as the initial samples. The samples are processed as follows: (1) financial industry samples are excluded, (2) ST and *ST companies during the sample deletion period, and (3) samples with missing data of main variables are removed. After the above processing, the final sample contains 16,101 observations.

The green patent data used in this paper were manually sorted by using Python software from the patent search website of the State Intellectual Property Office with the help of IPC classification numbers published in the 'Green List of International Patent Classifications' issued by WIPO in 2010. Given that the relevant financial data uses the data of the consolidated statement, to maintain the consistency of the data, the green patent data in this paper not only considers the green patent of the listed company itself but also includes the green patent output of its subsidiaries. The industry Classification Guidelines issued by the China Securities Regulatory Commission in 2012 were adopted to classify the industries to which enterprises belong. Other enterprise-level data came from the CSMAR database. Provincial-level data were obtained from the China Economic Network and the China Environmental Yearbook. To avoid the influence of extreme values on the results of this study, all continuous variables were curtailed at the 1% and 99% levels.

3.2 Definition of variables

3.2.1 Independent variable

The key to identifying the net effect of marine environmental regulation implementation is to construct appropriate experimental and control groups. As a marine environmental regulation system for coastal areas, the demonstration zone adopts a step-by-step pilot implementation method, so the demonstration zone can be divided into enterprises affected by marine environmental regulation and enterprises not affected by marine environmental regulation according to whether the enterprises are located in the demonstration zone. Specifically, based on the location of the 24 demonstration zones approved by the State Oceanic Administration, the enterprises located in the demonstration zones approved by the State Oceanic Administration in 2013 and 2015 were taken as the experimental group with 1 Treat variable, and the rest were taken as the control group with 0 Treat variable. After the marine environmental regulation is implemented, Post takes 1, otherwise, Post takes 0.

3.2.2 Dependent variable

The key to constructing the enterprise-level green technology innovation variable is in the identification of green patents of listed companies. Firstly, according to the IPC classification number published in the Green Patent List issued by WIPO, this paper identifies and captures the corresponding green patent information in the patent search website of the State Intellectual Property Office by year, including patent name, patent classification number, patent inventor and patent abstract. Secondly, to avoid the situation that the patents matched based on IPC classification number may not belong to green patent technology and overestimate the number of green patents of enterprises to a certain extent, we further build a green technology keyword dictionary with the help of national policy semantic expression related to green technology innovation. The final green patent data is screened by Python regular expression. Specifically, according to the definition of green technology in the 'Guiding Opinions on Building a Market-oriented Green Technology Innovation System' of the National Development and Reform Commission and the Ministry of Science and Technology, and the 'Green Technology Promotion Catalogue (2020)', we have selected 168 green technologies. These technologies include 'green', 'water saving', 'low carbon', 'environmentally friendly', 'pollution-free', 'recycling', and 'emission reduction', covering seven major fields. Colour technology-related vocabulary is used as the matching standard, and the final green patent data of listed companies are screened out according to the patent abstracts captured in the above step. Then, the enterprise green technology innovation index (GP) is constructed.

For the measurement of green technology innovation, the measurement indicators of the existing literature are mainly divided into two categories: one is the use of green patent application data and the other is the use of green patent grant data (Albino et al., 2014; Noailly and Smeets, 2015; Acemoglu et al., 2016; Aghion et al., 2016). On the one hand, this paper considers that a lag is present in patent authorization data, and it may be affected by many factors in the approval stage. On the other hand, this paper aims to investigate the willingness of enterprises in coastal areas to invest in green technology innovation or the degree of emphasis on green technology innovation under the background of the establishment of demonstration zones. Therefore green patent applications are more in line with the research objectives of this paper. We further statistical enterprise green patent grant data (GPG) as a proxy variable of green technology innovation output for the robustness test.

3.2.3 Control variables

Referring to existing authoritative studies (Berrone et al., 2013), this paper selected Size, Lev, ROA, Age, SOE, Cash, Top1, ShareBalance, Dual, Loss, and Ins as control variables. The selection and definition of specific variables are shown in Table 1.

3.3 Empirical model

To test the impact of the introduction of marine environmental regulations on enterprises' green technology innovation, this paper selects a semi-log model and draws on the research of Bertrand et al. (2004) to build the following model (1):

Dependent variable GP is the company's green technology innovation level. To avoid sample loss, this paper measured the number of green patent applications plus 1, taking the natural logarithm. Treat is a group dummy variable. When the company is located in the demonstration zone, the value is 1, otherwise the value is 0. Post is a time dummy variable. If the sample is in the year of the establishment of the demonstration zone (2013, 2015) and subsequent years, it is 1; otherwise, it is 0. Controls are a set of control variables that influence green technology innovation, in addition to annual (μ) and industry (η) fixed effects. We focus on the coefficient of the interaction term Treat*Post, which reflects the change in green technology innovation of enterprises located in the demonstration zone relative to other enterprises in the non-demonstration zone after the establishment of the demonstration zone. At the same time, to avoid the influence of aggregation effect on standard error at the firm level, cluster processing is carried out at the firm level during regression.

$$GP_{i,t} = \beta_0 + \beta_1 Treat_i * Post_t + Controls_{i,t} + \mu_t + \eta_j + \varepsilon_{i,t} \quad (1)$$

4 Empirical findings and analyses

4.1 Descriptive statistical analyses

Table 2 reports the descriptive statistical results of the main variables in this paper. The results show that the mean, median and standard deviation of GP during sample selection are 0.693, 0 and 1.071 respectively. The median is smaller than the sample mean, indicating that the problem of insufficient motivation for green technology innovation is common among listed companies in China, and there are obvious differences among companies. The mean value of Treat is 0.258, indicating that 25.8% of the enterprises in the sample are located in the demonstration zone. It can be seen that the enterprises subject to Marine environmental regulations occupy a certain proportion among the sample companies, indicating that a considerable proportion of listed companies will be affected by Marine environmental regulations. The descriptive statistical results of the remaining variables are consistent with the existing literature and are all within a reasonable range.

4.2 Multiple regression results

This paper uses a differentially differential model to test the impact of marine environmental regulations on green technology innovation in coastal areas, and the regression results are shown

TABLE 1 List of variable definitions.

Variable	Definition [Sources]
GP	Natural log of the number of green patent applications plus one
Treat	Whether it was a national marine ecological civilization demonstration zone.
Post	Whether policy implementation has started
Size	The natural logarithm of total assets.
Lev	Total debt divided by total assets.
ROA	Net income divided by total assets.
Age	The natural logarithm of the number of years the firm has been listed.
SOE	Indicator variable equal to one if the firm is a state-owned enterprise and 0 otherwise.
Cash	Cash flow from operations divided by total assets.
Top1	The proportion of firm shares held by the largest shareholder.
ShareBalance	Proportion of shares held by the 2nd-5th largest shareholders divided by proportion of shares held by the first largest shareholder.
Dual	Indicator variable equal to one if the chairman and the CEO of the company are the same person, and zero otherwise.
Loss	Indicator variable equal to one if the net profit less than 0, and zero otherwise.
Ins	The proportion of firm shares held by institutional investor.

TABLE 2 Summary Statistics.

VARIABLES	N	Mean	Std Dev	P10	P25	P50	P75	P90
GP	16,101	0.693	1.071	0.000	0.000	0.000	1.099	2.303
Treat	16,101	0.258	0.438	0.000	0.000	0.000	1.000	1.000
Post	16,101	0.158	0.365	0.000	0.000	0.000	0.000	1.000
Size	16,101	22.132	1.260	20.671	21.234	21.987	22.840	23.833
Lev	16,101	0.437	0.205	0.166	0.274	0.431	0.590	0.717
ROA	16,101	0.040	0.057	0.001	0.015	0.038	0.068	0.102
Age	16,101	2.116	0.903	0.693	1.609	2.303	2.833	3.091
SOE	16,101	0.370	0.483	0.000	0.000	0.000	1.000	1.000
Cash	16,101	0.048	0.075	-0.038	0.009	0.049	0.091	0.136
Top1	16,101	0.357	0.149	0.174	0.241	0.339	0.463	0.564
ShareBalance	16,101	0.673	0.567	0.097	0.225	0.520	0.968	1.462
Dual	16,101	0.271	0.444	0.000	0.000	0.000	1.000	1.000
Loss	16,101	0.094	0.292	0.000	0.000	0.000	0.000	0.000
Ins	16,101	0.472	0.245	0.106	0.287	0.490	0.667	0.779

This table reports the descriptive statistics of the sample. We winsorize the continuous variables at the 1st and 99th percentiles. All variables are defined in Table 1.

in Table 3. The table shows that when control variables are not added to Column (1) and only the fixed effects of year and industry are controlled, the coefficient of Treat*Post is significantly positive at the 10% level. The results in Column (2) show that the coefficient of Treat*Post is 0.094 and still significant at the 5% level after further adding the control variables of enterprise characteristics. These results show that compared with other enterprises, the demonstration zone has improved the level of green technology innovation of enterprises in coastal areas and led to an average increase of 9.4% in the number of green patent applications.

4.3 Robustness tests

To make the research conclusion of this paper more reliable and robust, the robustness test of the aforementioned regression was conducted as follows:

4.3.1 Propensity score matching

Major differences may occur between enterprises in the demonstration zone and other enterprises, so this paper further uses the PSM-DID method for testing. First, the experimental group and control group were matched 1:1 year by year by industry based on company characteristic variables such as enterprise Size (Size), enterprise age (Age), asset-liability ratio (Lev), return on assets (ROA), enterprise nature (SOE) and Sharebalance Dual Loss. Then the basic hypothesis test is re-conducted based on the matched samples, and the results are shown in Table 4. The results in Column (1) show that the coefficient of Treat*Post is 0.092, which is significant at the 5% level, consistent with these results.

4.3.2 Placebo tests

The time interval of the empirical analysis in this paper is 2008–2020. Considering that the results of this study may be caused by other potential events before and after the establishment of the demonstration zone, we further adjusted the time window to conduct a robustness test. This part adopts a placebo test. Regarding the research of (Bertrand et al., 2004), the sample interval was limited to 2008–2012, and 2011 was selected as the time when the assumed policy occurred. If no significant change occurred in the level of green technology innovation, the basic regression results in this paper are reliable. The test results are shown in Column (2) of Table 4. The coefficient of Treat*New_Post is not significant, indicating that the incentive effect of green technology innovation in marine regulation we observed is caused by the establishment of the demonstration zone, rather than other unobservable factors. The research conclusions are robust.

Second, due to the long research interval span in this paper, although the time fixed effect is controlled, considering that the results of this paper may be influenced by some random factors, the methods of Li et al. (2020) are used in this part to conduct a placebo test. To judge that the incentive effect of green technology innovation in marine regulation is caused by the establishment of the demonstration zone, rather than other random factors. The experimental group was randomly generated, the extracted placebo test was carried out, the original sample was randomly disordered, and the randomized interaction terms were used for regression. The kernel density distribution of simulated coefficients was drawn, as shown in Figure 1. The distribution of coefficients shows that the regression coefficients for Treat_new*Post are centrally distributed around the 0 point and are normally distributed, and are all to the left of the true values (0.094) in the main regression. Figure 1 shows that these regression results pass the placebo test, and the influence

TABLE 3 Main results.

	(1)	(2)
VARIABLES	GP	
*Treat*Post*	0.102*	0.094**
	(0.055)	(0.039)
Size		0.339***
		(0.000)
Lev		0.074
		(0.399)
ROA		0.693**
		(0.014)
Age		0.025
		(0.228)
SOE		0.085*
		(0.051)
Cash		-0.037
		(0.775)
Top1		-0.417**
		(0.029)
ShareBalance		-0.092**
		(0.016)
Dual		0.063*
		(0.051)
Loss		-0.023
		(0.560)
Ins		0.092
		(0.227)
Constant	-0.155**	-7.317***
	(0.028)	(0.000)
Year FE	Yes	Yes
Industry FE	Yes	Yes
Observations	16,101	16,101
Adjusted R-squared	0.163	0.318

t-statistics in parentheses.
***p<0.01, **p<0.05, *p<0.1.

TABLE 4 PSM and Placebo test.

	(1)	(2)
VARIABLES	GP	GP
*Treat*Post*	0.092**	
	(0.048)	
*Treat*New_Post*		0.073
		(0.194)
Size	0.342***	0.229***
	(0.000)	(0.000)
Lev	0.102	-0.049
	(0.357)	(0.600)
ROA	1.034***	0.362
	(0.005)	(0.308)
Age	0.019	0.032
	(0.445)	(0.190)
SOE	0.053	0.016
	(0.323)	(0.708)
Cash	0.002	-0.105
	(0.991)	(0.446)
Top1	-0.642***	-0.192
	(0.005)	(0.363)
ShareBalance	-0.124***	-0.035
	(0.008)	(0.408)
Dual	0.115***	0.116***
	(0.007)	(0.005)
Loss	0.011	0.039
	(0.837)	(0.446)
Ins	0.052	0.083
	(0.577)	(0.370)
Constant	-7.284***	-4.893***
	(0.000)	(0.000)
Year FE	Yes	Yes
Industry FE	Yes	Yes
Observations	8,228	4,795
Adjusted R-squared	0.318	0.214

t-statistics in parentheses.
***p<0.01, **p<0.05, *p<0.1.

of marine environmental regulations on the green innovation of enterprises in coastal areas does not come from other random factors. The above research conclusions are robust.

4.3.3 Parallel trend test

Using the event study method proposed by Jacobson et al. (1993) for reference, this paper added the cross term of each year dummy variable and group dummy variable, and took the year before the establishment of the demonstration zone as the benchmark period to investigate its dynamic impact on the green technology innovation level of enterprises in coastal areas. The regression results are shown in Column (1) of Table 5. The results showed that the coefficients of Pre_2, Pre_3, Pre_4, Pre_5, Pre_6 and Pre_7 were not significant, indicating that there was no significant difference in green technology innovation between the

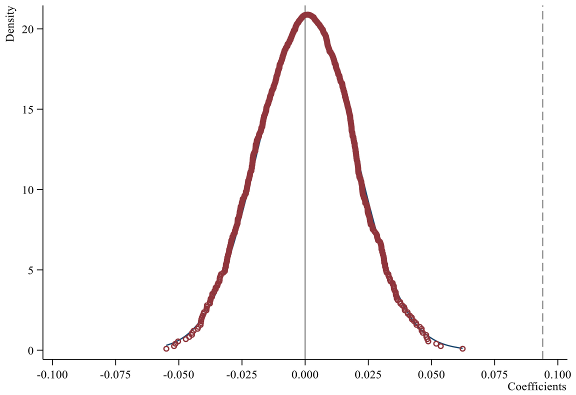

FIGURE 1
The kernel density distribution of simulated coefficients.

experimental group and the control group before the formal establishment of the demonstration zone, satisfying the parallel trend hypothesis. Current, Post_1 and Post_2, are all significant at the 5% level and their coefficients increase, indicating that with the establishment of the demonstration zone, the effect of this policy is increasing. However, the coefficients of Post_6 and Post_7 are significantly negative, indicating that the effect of this policy is not long-term and a negative effect is found on enterprises' green technology innovation after many years of implementation.

4.3.4 Alternative the dependent variable

To avoid the impact of measurement errors in the selection of indicators on the empirical results of this paper, this paper selects other alternative indicators to test the robustness of the subject hypothesis. Referring to the research of Aghion et al. (2016) and Acemoglu et al. (2016), we use green patent grant data to measure enterprise green technology innovation. Specifically, this paper calculates the number of patents applied for and granted by the company in the current year by adding 1 to take the natural logarithm to replace GP, and the regression results are shown in Column 1 of Table 6. The results show that the Treat*Post coefficient in Column (1) is still significantly positive, indicating the robustness of these empirical results.

4.3.5 Alternative estimation model

The number of patents used in this paper has a large number of zeros with the feature of truncated data. Considering the potential model setting bias of the linear regression model, this part uses the Tobit model, referencing to Tobin (1958), to further test the impact of marine environmental regulation on the green technology innovation of enterprises in coastal areas. The regression results are shown in Table 6. The Treat*Post coefficient in Column (2) is still significantly positive, indicating the robustness of the above empirical results.

4.3.6 Controlling city-level factors

Considering that regional environmental governance factors may affect enterprises' green technology innovation behaviour, to alleviate endogenous problems caused by missing variables, this paper further controls factors at the regional level. It includes the degree of government intervention (GI, general revenue of government finance/gross regional product), the degree of financial development (FD, loan balance of financial institutions at the end of the year/gross regional product), and the industrial

TABLE 5 Parallel trend test.

	(1)
VARIABLES	GP
Pre_7	0.145
	(0.214)
Pre_6	0.134
	(0.175)
Pre_5	0.054
	(0.512)
Pre_4	0.145
	(0.150)
Pre_3	0.044
	(0.428)
Pre_2	0.095
	(0.132)
Current	0.156**
	(0.040)
Post_1	0.153**
	(0.039)
Post_2	0.179**
	(0.020)
Post_3	0.139
	(0.184)
Post_4	0.169*
	(0.063)
Post_5	0.127
	(0.231)
Post_6	-0.251***
	(0.004)
Post_7	-0.292**
	(0.018)
Year FE	Yes
Industry FE	Yes
Observations	16,101
Adjusted R-squared	0.165

t-statistics in parentheses.
***p<0.01, **p<0.05, *p<0.1.

structure (IS, value-added of tertiary industry/gross regional product). The regression results are shown in column (1) of Table 7. Due to the absence of macro data in some cities, the sample size of this regression is smaller than that of the main regression. The regression results in Table 7 show that the regression coefficient of Treat*Post is still significantly positive, which is consistent with the aforementioned empirical results, indicating that the previous research conclusions are reliable.

4.3.7 Rule out other contemporaneous policies

During the establishment of the demonstration zone, China also introduced other environmental regulation policies, which have the same policy attributes of environmental protection and sustainable development as the construction of the national Marine ecological civilization demonstration zone, which may interfere with the research results of this paper.

In 2012, in the face of the dual pressure of environmental protection and economic growth, the China Banking Regulatory Commission issued the "Green Credit Guideline" and began to try to incorporate the concept of environmental protection into credit policies. The policy makes clear requirements on the responsibilities and operational processes of banking financial institutions in terms of environmental and social risks, urging banks to effectively incorporate environmental risks into their lending decisions, and tightening credit for industries with high pollution, high energy consumption and overcapacity. In 2013, to promote circular production mode and green lifestyle, further promote green development and low-carbon development through circular development, and improve the ecological civilization level of cities (counties). The National Development and Reform Commission officially identified 40 regions such as Yanqing County of Beijing as the 2013 national circular economy demonstration cities (counties) to create regions, aiming to build them into a national circular economy development model and set a model for ecological civilization construction. The introduction of these two policies may have an impact on our research results.

First of all, this paper will belong to the "Listed companies Environmental Protection Verification Industry Classification Management List" issued by the Ministry of Environmental Protection in 2008 involved in high-pollution, high-energy, overcapacity industry enterprises in the sample to be excluded, the remaining coastal area enterprises according to whether they are located in the demonstration zone, divided into experimental group and control group for re-testing, if the same results are still observed. It shows that the more active green technology innovation of enterprises in demonstration areas is indeed affected by Marine environmental regulations, thus excluding the competitive explanation of the Green Credit Guidelines in the same period. The regression results are shown in column (2) of Table 7. The regression coefficient of Treat*Post in column (1) is still significantly positive, basically consistent with the aforementioned empirical results, which excludes the possible influence of the Green Credit Guidelines on the conclusion of this paper.

Secondly, this paper selects the samples of 40 coastal cities outside the " National Circular Economy Demonstration City" and further divides them into experimental groups and control groups for re-testing according to whether they are located in the economy demonstration cities. If the same results are still observed, it indicates that our results are robust. Thus, the competitive explanation of "National Circular Economy Demonstration City" is excluded. The regression results are shown in column (3) of Table 7. The regression coefficient of Treat*Post in column (3) is still significantly positive, which is consistent with the aforementioned empirical results, indicating that enterprises

TABLE 6 Alternative the dependent variable and estimation model.

	(1)	(2)
VARIABLES	GPG	GP
*Treat*Post*	0.066*	0.191**
	(0.096)	(0.020)
Size	0.292***	0.721***
	(0.000)	(0.000)
Lev	0.087	0.144
	(0.265)	(0.490)
ROA	0.596**	1.423**
	(0.020)	(0.026)
Age	0.017	-0.014
	(0.345)	(0.768)
SOE	0.069*	0.237***
	(0.069)	(0.009)
Cash	-0.057	-0.166
	(0.619)	(0.612)
Top1	-0.347**	-0.882**
	(0.040)	(0.029)
ShareBalance	-0.079**	-0.226***
	(0.020)	(0.006)
Dual	0.049*	0.088
	(0.094)	(0.199)
Loss	-0.014	-0.114
	(0.691)	(0.223)
Ins	0.073	0.055
	(0.270)	(0.755)
Constant	-6.321***	-17.660***
	(0.000)	(0.000)
Year FE	Yes	Yes
Industry FE	Yes	Yes
Observations	16,101	16,101
Adjusted R-squared	0.303	
Pseudo R2		0.154

t-statistics in parentheses.
***p<0.01, **p<0.05, *p<0.1.

TABLE 7 Controlling city-level factors and other policies.

	(1)	(2)	(3)
VARIABLES	GP	GP	GP
*Treat*Post*	0.104**	0.094**	0.090**
	(0.029)	(0.038)	(0.047)
$Policy_{GC}$**After*		0.006	
		(0.899)	
NCEDC			-0.072
			(0.210)
Size	0.342***	0.339***	0.339***
	(0.000)	(0.000)	(0.000)
Lev	0.069	0.074	0.078
	(0.450)	(0.400)	(0.371)
ROA	0.626**	0.694**	0.701**
	(0.034)	(0.014)	(0.013)
Age	0.026	0.024	0.024
	(0.221)	(0.230)	(0.243)
SOE	0.086*	0.085*	0.090**
	(0.058)	(0.051)	(0.038)
Cash	0.018	-0.037	-0.040
	(0.893)	(0.774)	(0.750)
Top1	-0.364*	-0.418**	-0.425**
	(0.070)	(0.029)	(0.026)
ShareBalance	-0.084**	-0.092**	-0.093**
	(0.039)	(0.016)	(0.015)
Dual	0.084**	0.064*	0.064**
	(0.015)	(0.050)	(0.047)
Loss	-0.035	-0.023	-0.022
	(0.396)	(0.561)	(0.580)
Ins	0.076	0.092	0.093
	(0.353)	(0.226)	(0.219)
GI	-0.889**		
	(0.027)		
FD	-0.031		
	(0.462)		
IS	0.876***		
	(0.001)		
Constant	-7.654***	-7.314***	-7.311***
	(0.000)	(0.000)	(0.000)
Year FE	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes

(Continued)

TABLE 7 Continued

	(1)	(2)	(3)
VARIABLES	GP	GP	GP
Observations	14,263	16,101	16,101
Adjusted R-squared	0.333	0.318	0.318

t-statistics in parentheses.
***p<0.01, **p<0.05, *p<0.1.

located in the demonstration zones are still more active in green technology innovation after controlling for the effect of ‘National Circular Economy Demonstration City’. This excludes the possible influence of the “National Circular Economy Demonstration City” established in the same year on the conclusions of this paper.

5 Further analyses

5.1 Mechanism analyses

China’s environmental policy is usually top-down. The four main tasks for the creation of a marine ecological civilization demonstration zone include: optimizing the industrial structure of coastal areas and transforming the mode of development; strengthening the control of pollutant emissions into the sea and improving the quality of the marine environment; strengthening the protection of marine ecology and safeguarding marine ecological security; and fostering the awareness of marine ecological civilization and establishing the concept of marine ecological civilization. We hypothesize that an increase in green technology innovation following the establishment of *Demonstration Zones* may stem from either local government environmental concerns or the increased need for upgrading the industrial structure. We thus further test these two potential channels through which marine environmental regulation affects green technology innovation.

5.1.1 Local governments’ attention to the environment

In cities with demonstration zones, the protection of marine ecosystems becomes even more important. The demonstration zones set out detailed requirements for the management and construction of local marine ecological environmental protection, and indicate that those that fail the assessment will be withdrawn. In the face of the assessment pressure of the construction objectives of the demonstration zones, the attributes of local government as ‘political personnel’ make them rearrange the weights of various political behaviours in their utility functions to maximize their interests. Therefore, we expect that the construction of the demonstration zones increases the pressure and motivation of local governments for environmental governance, promotes local government to be more environmentally concerned, and in turn, drive local firms to improve their green technological innovation.

This paper holds that Marine environmental regulation represented by demonstration zones will have a positive impact on enterprises’ green technology innovation by increasing local government's attention to the environment. Concerning the existing literature (Chen et al., 2018), this paper selects the occurrence times of environment-related words in the work report of the prefecture-level city government plus 1, and takes the natural logarithm as the proxy variable of the prefecture-level city government's attention to the environment (GEC). The results are shown in column (1) of Table 8. It shows that the regression coefficient of Treat*Post is significantly positive, indicating that Marine environmental regulation increases the local government's concern about the environment, and thus has a positive impact on the green technology innovation of enterprises in coastal areas.

5.1.2 Need for upgrading the industrial structure

One of the main tasks of creating the marine ecological civilization demonstration zones is to optimize the industrial structure of coastal areas and shift the development pattern. Enterprises, as 'economic agents' also adopt economic behaviours that are characterized by heterogeneity based on discretionary choices based on the principle of maximizing their interests (Milani, 2017). After the introduction of the marine environmental policies, green and low-carbon emerging industries can enjoy corresponding policy dividends and continue to promote enterprises to carry out green upgrading (Zhou et al., 2017). For traditional industries with high energy consumption and high pollution, higher environmental taxes and penalties increase the production cost of traditional industries with high pollution, so they will seek greener and low-carbon production methods in an unfavourable business environment to achieve their own green and low-carbon transformation. Therefore, the green orientation of the marine environmental regulation promotes the green transformation and upgrading of industrial structure, which in turn positively affects the green behaviour of enterprises, that is, the level of green technology innovation.

This paper holds that Marine environmental regulation represented by demonstration zones will have a positive impact on enterprises' green technology innovation by optimizing the industrial structure. This paper refers to existing literature to measure industrial structure upgrading. Specifically, the measure of industrial structure upgrading (ISU) is the proportion of the added value of the primary industry in GDP *1+ the proportion of the added value of the secondary industry in GDP *2+ the proportion of the added value of the tertiary industry in GDP *3. The result is shown in column (2) of Table 8. It shows that the regression coefficient of Treat*Post is significantly positive, indicating that marine environmental regulation promotes the upgrading of industrial structure and thus has a positive impact on the green technology innovation of enterprises in coastal areas.

TABLE 8 Mechanism tests.

	(1)	(2)
VARIABLES	GEC	ISU
*Treat*Post*	0.455***	0.313***
	(0.000)	(0.000)
Size	-0.035	-0.025
	(0.161)	(0.126)
Lev	-0.190	-0.128
	(0.180)	(0.163)
ROA	1.240***	0.753**
	(0.007)	(0.010)
Age	0.062*	0.045**
	(0.059)	(0.036)
SOE	0.352***	0.251***
	(0.000)	(0.000)
Cash	-0.714***	-0.467***
	(0.001)	(0.001)
Top1	0.235	0.201
	(0.401)	(0.270)
ShareBalance	0.066	0.037
	(0.289)	(0.358)
Dual	0.008	-0.004
	(0.900)	(0.921)
Loss	0.105*	0.069*
	(0.092)	(0.082)
Ins	0.111	0.035
	(0.446)	(0.718)
Constant	3.044***	2.022***
	(0.000)	(0.000)
Year FE	Yes	Yes
Industry FE	Yes	Yes
Observations	16,101	16,101
Adjusted R-squared	0.0777	0.0874

t-statistics in parentheses.
***p<0.01, **p<0.05, *p<0.1.

5.2 Cross–sectional analyses

5.2.1 Whether the city is resource-based

Resource-based cities have a higher need for industrial restructuring. Resource-based cities were formed as a result of China's continuous industrial development. Most of these resource-based cities use the mining industry as their pillar industry and thus face serious environmental pollution problems. Resource-rich cities tend to pay more attention to the development of resource-based industries and carry out excessive resource exploitation and investment in high-pollution energy projects, thus causing damage to the marine ecosystem and facing greater pressure for upgrading (Yu et al., 2008; Dong et al., 2017). Therefore, resource-based cities can be more sensitive to marine environmental regulation. In resource-based cities, enterprises in the demonstration area have stronger incentives to pursue green upgrading for the sustainable development of marine ecosystems.

On this basis, this paper investigates whether the impact of marine environmental regulation on green technology innovation of firms in coastal areas varies with the development mode of the city in which the enterprises is located. According to the list of resource-based cities published in the National Plan for Sustainable Development of Resource-Based Cities (2013–2020), the research samples were divided into resource-based cities and non-resource-based cities, and then grouped regression was carried out. The results are shown in Table 9. It shows that the impact of marine environmental regulations on green technology innovation of enterprises in coastal areas is stronger in resource-based cities than in non-resource-based cities.

5.2.2 Dependence on the marine economy

If the importance of the marine industry in the regional economy is greater, then the local government pays more attention to the protection of the marine ecosystem. According to the resource dependence theory proposed by Pfeffer and Salancik (2003), organizations depend on resources in their environment and try to manage this dependence to ensure survival. In areas highly dependent on the Marine economy, enterprises are more susceptible to changes in the Marine environment and therefore more sensitive to Marine environmental regulations. Meanwhile, the institutional stress theory proposed by DiMaggio and Powell (1983)] holds that organizations will exhibit similar behaviours under the pressure of the institutional environment. In areas with high dependence on the marine economy, Marine environmental regulation, as a kind of institutional pressure, can more strongly affect the local government's motivation to protect the marine ecology, which in turn affects enterprises' behaviours Berrone et al. (2013).

On this basis, this paper investigates whether the impact of marine environmental regulation on green technology innovation of firms in coastal areas varies with the degree of regional dependence on the marine economy. The research sample was divided into two groups using the median ratio of marine GDP to provincial GDP as the partitioning criterion. The results are shown in Table 10. As shown in Table 10, the results show that the higher the regional dependence on the marine economy, the more significant the impact of marine environmental regulation on enterprises' green technology innovation.

5.2.3 Green finance development

In China, green finance is the main source of financial support for enterprises' green transformation. According to the resource-based theory, the innovation ability of an enterprise depends on its available resources. As an important external resource, green finance can provide necessary financial support for enterprises' green technology innovation (Scholtens, 2017). In regions with a higher level of green finance development, enterprises are more likely to obtain low-cost green credit, green bonds and other financing tools (Borghesi et al., 2015), thus easing the financial constraints in the innovation process. At the same time, according to signal theory (Michael, 1973), a good green financial environment signals to investors that the government attaches importance to environmental protection and sustainable development, and helps attract more capital to the green innovation sector (Zerbib, 2019). Therefore, in provinces with higher levels of green finance development, where enterprises have access to more adequate and convenient financial support to implement innovative activities, marine environmental regulations are more likely to motivate enterprises to green technological innovation.

On this basis, this paper investigates whether the impact of marine environmental regulation on green technology innovation of firms in coastal areas varies with the level of regional green finance development. Regarding existing literature (Wang and Zhang, 2023), the research sample was divided into two groups using the median of the Green Finance Index as the partition criterion. The results are shown in Table 11. Table 11 shows that in provinces with higher levels of green finance development, marine environmental regulation has a more significant impact on enterprises' green technology innovation.

TABLE 9 Whether or not it is a resource-based city.

VARIABLES	(1)	(2)
	GP	
	No	Yes
*Treat*Post*	0.086*	0.803***
	(0.058)	(0.000)
Controls and Constant	Yes	Yes
Year, and Industry FE	Yes	Yes
Observations	15,025	1,076
Adjusted R-squared	0.326	0.261
Tests of difference between groups	Yes (χ^2 = 15.96; P=0.000)	

t-statistics in parentheses.
***p<0.01, **p<0.05, *p<0.1.

TABLE 10 Dependence on the maritime economy.

VARIABLES	(1)	(2)
	GP	
	Low	High
*Treat*Post*	-0.039	0.127**
	(0.625)	(0.022)
Controls and Constant	Yes	Yes
Year, and Industry FE	Yes	Yes
Observations	6,963	9,138
Adjusted R-squared	0.297	0.343
Tests of difference between groups	Yes (χ2 = 2.98; P=0.084)	

t-statistics in parentheses.
***p<0.01, **p<0.05, *p<0.1.

5.2.4 Whether or not it is marine-related firm

The principal place of concern for the construction of a marine ecological civilisation is still the protection of the marine ecological environment. Marine-related enterprises, because of their special characteristics, are more directly dependent on marine resources and may therefore be more sensitive to marine environmental regulations. In addition, based on the dynamic capability theory (Teece et al., 1997) ocean-related enterprises may have developed stronger environmental perception and coping ability due to long-term interaction with the Marine environment, which enables them to more effectively transform environmental regulation into innovation impetus (Li et al., 2018). Therefore, marine-related enterprises are likely to engage in more aggressive green technology innovation when faced with stricter marine environmental regulations.

On this basis, this paper investigates whether the impact of marine environmental regulation on green technology innovation of enterprises in coastal areas varies with the nature of their operations. Specifically, this paper identifies whether the enterprise is a marine-related listed company from its business scope (Shi et al., 2024). The results are shown in Table 12. Table 12 shows that the impact of marine environmental regulation on enterprises' green technological innovation is more pronounced among marine-related firms.

5.2.5 Financial constraints

Our results thus far support the conclusion that when local marine environmental regulations become stricter, enterprises respond with aggressive green technological innovations. However, this optimal response can be limited by a lack of resources. Innovative activities require continuous financial support (Hall and Lerner, 2010). Financially constrained firms may lack the funds to invest in R&D (Brown et al., 2009), which weakens the impact of environmental regulations on enterprises' green technology innovation (Ghisetti et al., 2017). By contrast, enterprises that do not have financial constraints are more affordable to undertake green technology innovation activities (Aghion et al., 2016; Costantini et al., 2017).

On this basis, this paper investigates whether the impact of marine environmental regulation on green technology innovation of enterprises in coastal areas varies with financial constraints. Referring to Kaplan and Zingales (1997), this paper uses the KZ index to measure the degree of financial constraints. The research sample was divided into two groups using the median of the KZ index as the partition criterion. The results are listed in Table 13. The results show that the impact of marine environmental regulation on green technology innovation of enterprises in coastal areas is significant only in low levels of financial constraints.

5.3 How do enterprises adjust technological innovation activities under marine environment regulation?

Enterprise technological innovation exists in a direction (Hicks, 1963). Enterprises can choose to carry out environmentally beneficial 'clean' innovation or non-green technological innovation when allocating innovation resources (Aghion et al., 2016). The former emphasizes the realization of the economic and environmental benefits of a win-win situation. The latter is limited to the improvement of corporate profits and does not incorporate environmental protection into innovation investment decisions. Enterprises can also choose whether to do R&D on their own or in cooperation with others. For independent innovation, enterprises can fully capture the benefits of technological innovation and prevent the leakage of key technologies. For collaborative innovation, firms can improve innovation efficiency and share R&D risks and costs by establishing R&D alliances (Hennart, 1988).

On this basis, we further investigate how enterprises in coastal areas adjust the allocation of technological innovation resources and accelerate their green technological innovation activities from the dimensions of technological innovation structure and innovation mode. For the measurement of enterprise innovation

TABLE 11 Green finance development.

VARIABLES	(1)	(2)
	GP	
	Low	High
*Treat*Post*	-0.011	0.139**
	(0.863)	(0.023)
Controls and Constant	Yes	Yes
Year, and Industry FE	Yes	Yes
Observations	9,047	7,054
Adjusted R-squared	0.276	0.378
Tests of difference between groups	Yes ($\chi 2$ = 3.14; P=0.077)	

t-statistics in parentheses.
***p<0.01, **p<0.05, *p<0.1.

TABLE 12 Whether or not it is a marine-related firm.

VARIABLES	(1)	(2)
	GP	
	No	Yes
*Treat*Post*	0.074	0.252*
	(0.120)	(0.064)
Controls and Constant	Yes	Yes
Year, and Industry FE	Yes	Yes
Observations	14,753	1,348
Adjusted R-squared	0.311	0.436
Tests of difference between groups	Yes ($\chi 2$ = 5.52; P=0.019)	

t-statistics in parentheses.
***p<0.01, **p<0.05, *p<0.1.

structure, this paper further subdivided enterprises' green patents into green invention patents and green utility model patents. For the measurement of enterprises' choice of green innovation methods, this paper uses the number of green patents independently applied by enterprises and the number of green patents jointly applied by other entities, respectively, to construct the independent innovation and cooperative innovation indicators of enterprises according to the applicant information of green patents.

The regression results are shown in Table 14. Columns (1) -(4) are regression results of Marine regulation on patent applications for green invention, patent applications for green utility models, independent innovation and joint innovation. The establishment of demonstration zones significantly increased the number of green invention patents of enterprises in coastal areas but had no significant impact on green utility model patent applications. Therefore, we believe that the establishment of demonstration zones leads local enterprises to pay more attention to the improvement of the quality of green patents, which is manifested in the increase in the number of green invention patents. For the choice of innovation methods, the paper finds that the establishment of the demonstration zone provokes an increase in the number of enterprises' independent innovations in the coastal region, which reflects that enterprises are more prone to choose to increase their internal R&D investment rather than to co-operate with others.

5.4 Marine environmental regulation and high-quality development of regional economy

The purpose of marine environmental regulation is to support the construction of ecological civilization and ensure high-quality economic development. Therefore, this paper further tests whether the positive impact of marine environmental regulation on the green technology innovation of enterprises in coastal areas can ultimately contribute to the high-quality development of the regional economy. More specifically, we first explored the impact of marine environmental regulations on regional green technology innovation. Secondly, we test the impact of marine environmental regulation on the high-quality development of the regional economy in two dimensions: economic effect and environmental effect.

Firstly, referring to Fu et al. (2018), we use the number of green patents aggregated at the city level to measure the level of regional green technology innovation (GP_city). Secondly, we use the logarithm of per capita GDP to measure the economic effect (GDP) and unit energy consumption (total energy consumption of 10,000 tons of standard coal/real GDP of 10,000 yuan) to measure the energy-saving effect (Energy). For control variables, we refer to existing studies, control population density Pdensity (regional resident population/urban area), foreign investment level OE (actual utilization of foreign capital/gross regional product), government intervention level GI (government general revenue/ government general expenditure), government investment intensity Investment (government investment intensity = fixed assets investment/local general expenditure), environmental regulation ER (general industrial solid waste comprehensive utilization rate).

The regression results are shown in Table 15. Column (1) shows that after controlling a series of urban characteristic variables and year fixed effects, marine environmental regulation increases regional green technology innovation, and the coefficient of Treat*Post is 0.267, which is significantly positive at the 5% level. The test results in column (2) show that, based on economic growth, the regression coefficient of Treat*Post*GP_city is 0.048, which is significantly positive at the 1% level. Based on the energy-saving effect, the regression coefficient of Treat*Post*GP_city is −0.003, which is significantly negative at the 1% level. The above results show that after the implementation of marine environmental regulations, the economic growth rate and energy-saving effect are more obvious in areas with a higher proportion of enterprises' green technology innovation, indicating that it is the marine environmental regulations that are effective.

TABLE 13 Financial constraints.

VARIABLES	(1)	(2)
	GP	
	Low	High
*Treat*Post*	0.131**	0.048
	(0.020)	(0.418)
Controls and Constant	Yes	Yes
Year, and Industry FE	Yes	Yes
Observations	7,673	8,428
Adjusted R-squared	0.315	0.330
Tests of difference between groups	Yes (χ^2 = 3.38; P=0.066)	

t-statistics in parentheses.
***p<0.01, **p<0.05, *p<0.1.

6 Conclusion and discussion

Green technology innovation is a key force in achieving high-quality economic development. This paper explores whether the establishment of demonstration zones (as a forerunner of China's marine environmental policy system) can facilitate enterprises' green technological innovation. The research finds that in coastal areas, compared with enterprises in non-demonstration areas, enterprises located in demonstration areas have significantly increased their green technology innovation activities, and this conclusion remains valid after a series of robustness tests. Furthermore, the impact of marine environmental regulation on enterprises' green technology innovation is more significant in resource-based cities, areas with high marine economic dependence and high green finance development, as well as in enterprises with low financial constraints and marine-related enterprises. Under the requirements of marine environmental regulations, the quality of green patents of enterprises in coastal

TABLE 14 Types of innovative activities.

	(1)	(2)	(3)	(4)
VARIABLES	GPI	GPU	GP_stand-alone	GP_joint
*Treat*Post*	0.071*	0.039	0.080*	0.023
	(0.067)	(0.268)	(0.064)	(0.331)
Size	0.274***	0.229***	0.297***	0.130***
	(0.000)	(0.000)	(0.000)	(0.000)
Lev	-0.002	0.137**	0.132	-0.061
	(0.975)	(0.041)	(0.107)	(0.132)
ROA	0.541**	0.482**	0.746***	-0.052
	(0.022)	(0.027)	(0.007)	(0.689)
Age	0.023	0.016	0.023	0.010
	(0.165)	(0.325)	(0.238)	(0.320)
SOE	0.084**	0.044	0.079*	0.029
	(0.023)	(0.187)	(0.056)	(0.144)
Cash	-0.056	-0.046	-0.088	0.046
	(0.599)	(0.648)	(0.467)	(0.457)
Top1	-0.344**	-0.270*	-0.392**	-0.073
	(0.035)	(0.063)	(0.030)	(0.498)
ShareBalance	-0.061*	-0.065**	-0.080**	-0.024
	(0.059)	(0.026)	(0.027)	(0.261)
Dual	0.080***	0.024	0.053*	0.032*
	(0.003)	(0.347)	(0.085)	(0.059)
Loss	-0.025	-0.014	-0.012	-0.033*
	(0.446)	(0.652)	(0.755)	(0.086)
Ins	0.087	0.074	0.074	0.024
	(0.161)	(0.192)	(0.300)	(0.519)
Constant	-5.917***	-5.004***	-6.433***	-2.808***
	(0.000)	(0.000)	(0.000)	(0.000)
Year FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Observations	16,101	16,101	16,101	16,101
Adjusted R-squared	0.275	0.279	0.291	0.152

t-statistics in parentheses.
***p<0.01, **p<0.05, *p<0.1.

areas significantly improves, which is reflected in the significant increase in the number of green invention patents. As for the choice of innovation mode, marine environmental regulation leads to an increase in the number of independent innovations of enterprises in coastal areas. Finally, we find that the positive impact of marine environmental regulation on green technology innovation can significantly increase regional GDP, and significantly reduce energy consumption, which indicates that the positive impact of green technology innovation on enterprises can promote high-quality economic development in coastal areas.

TABLE 15 Marine environmental regulation and high-quality development of regional economy.

	(1)	(2)	(3)
VARIABLES	GP_city	GDP	Energy
*Treat*Post*	0.267**		
	(0.011)		
GP		0.165***	-0.954***
		(0.000)	(0.000)
*Treat*Post*GP_city*		0.048***	0.102***
		(0.000)	(0.000)
Pdensity	0.499***	-0.258***	-0.397***
	(0.000)	(0.000)	(0.000)
OE	17.971***	5.075***	-2.989
	(0.000)	(0.000)	(0.220)
GI	-6.082***	-3.197***	11.975***
	(0.000)	(0.000)	(0.000)
Investment	-0.007	0.014***	-0.010
	(0.539)	(0.000)	(0.689)
ER	0.000	-0.000	0.007***
	(0.677)	(0.211)	(0.009)
Constant	0.722***	11.223***	8.448***
	(0.000)	(0.000)	(0.000)
Year FE	Yes	Yes	Yes
Observations	3,634	3,634	3,634
Adjusted R-squared	0.627	0.741	0.477

t-statistics in parentheses.
***p<0.01, **p<0.05, *p<0.1.

The research conclusions of this paper provide empirical evidence for the effects of marine environmental regulations at the micro and macro levels and will provide scientific decision-making basis for promoting marine environmental policy innovation, green technology innovation of enterprises in coastal areas, enhancing the green core competitiveness of industries in coastal areas and promoting the sustainable development of the marine economy.

This study contributes to the existing literature in several ways and opens avenues for future research. Firstly, it extends the understanding of environmental regulation effects by focusing specifically on marine environmental policies, an area that has received less attention compared to general environmental regulations. Secondly, our findings provide empirical support for the Porter Hypothesis in the context of marine environmental regulations, demonstrating that well-designed policies can indeed stimulate innovation and improve both economic and environmental outcomes.

From a policy perspective, this paper finds that the construction of demonstration zones is an effective marine environmental policy, promoting the increase of green technology innovation of enterprises in coastal areas and driving regional economic development and environmental improvement, thereby providing empirical evidence for the effectiveness of the establishment of demonstration zones. Following the demonstration zone, the government can also actively explore and practice the construction of marine environmental ecological civilization and further improve the marine environmental policy system to encourage green technology innovation activities of enterprises. At the same time, enterprises are the main body of green technology innovation, which is crucial to deepening the construction of ecological civilization and promoting high-quality economic development. This paper finds that micro-enterprises green technology innovation is the key driving force for the high-quality development of the regional economy.

Therefore, the state should speed up the cultivation of leading enterprises in green technology innovation, give play to the leading role of leading enterprises and guide more enterprises to participate in green technology innovation.

However, this research also has limitations. For instance, while we focused on coastal areas and demonstration zones, future research could explore the spillover effects of these policies on inland regions or non-demonstration areas. Additionally, longitudinal studies could be conducted to examine the long-term sustainability of the observed positive effects. Furthermore, comparative studies across different countries with similar marine environmental policies could provide insights into the generalizability of our findings.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

JJ: Conceptualization, Formal Analysis, Investigation, Writing – original draft. HS: Data curation, Methodology, Software, Writing – review & editing.

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

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