frontiers | Frontiers in Environmental Science

TYPE Original Research
PUBLISHED 07 February 2023
DOI 10.3389/fenvs.2023.1092712

OPEN ACCESS

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SPECIALTY SECTION
This article was submitted to Water and Wastewater Management, a section of the journal Frontiers in Environmental Science

RECEIVED 08 November 2022
ACCEPTED 19 January 2023
PUBLISHED 07 February 2023

CITATION
Wu F, Cui F and Liu T (2023), Empirical study on green development of marine economy driven by marine scientific and technological innovation and its influencing factors.
Front. Environ. Sci. 11:1092712.
doi: 10.3389/fenvs.2023.1092712

Empirical study on green development of marine economy driven by marine scientific and technological innovation and its influencing factors

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In this study, the green development of marine economy driven by marine scientific and technological innovation is empirically studied and the influencing factors are analyzed. The results show that the development of marine science and technology is significantly positively correlated with the green development of marine economy as a whole, and each input variable has a promoting effect on economic development, but with varied degree of effect. The analysis on the growth models of “Circum-Bohai Sea Economic Zone,” “Yangtze River Delta Economic Zone” and “Pearl River Delta Economic Zone” shows that at present, science and technology in each marine economic zone play an obvious role in promoting economic development, and each input variable plays a different role in promoting the green development of regional marine economy. With the help of threshold panel model, the influences of five factors, namely opening to the outside world, government investment, financial development, human capital and technology investment, on the green development of marine economy driven by marine scientific and technological innovation are investigated, and it is concluded that all kinds of external influencing factors will interfere with the role of marine scientific and technological innovation and achieve the effect of promoting or restricting it.

KEYWORDS

marine scientific and technological innovation, green development of marine economy, threshold model, influencing factors, technological innovation

Introduction

As the future development is more about the development of marine industry, the construction of first-class seaports is imminent. Only by establishing a perfect modern marine industry system, effectively improving the marine ecological environment and achieving green and sustainable development can contributions be made to the development of our country for truly becoming a powerful marine nation. Marine economy is closely related to national construction, effectively improve the quality of marine economy, make full use of this treasure house, obtain continuous resources, make contributions to national economy, and occupy a certain position in international competition. The research results on marine science and technology innovation and green development of marine economy can be divided into four aspects. First, the marine science and technology innovation and the marine economy green development correlation Research (Chen and Ma, 2020; Cu, 2020; Wang et al., 2021). Second, the research on coordinated development of marine science and technology innovation and Marine

TABLE 1 MEC evaluation indicator system.

Level 1 indicators	Level 2 indicators	Level 3 indicators	Weights
MEC	Total marine economy	Proportion of added value of marine industry in the whole country	0.1634
		Per capita marine GDP	0.0453
		The proportion of total investment in fixed assets of marine industry in total investment in fixed assets of China	0.0240
		The proportion of the number of sea-related employees in the number of sea-related employment in the country	0.1606
	Marine economic structure	The ratio of the added value of the marine primary industry to the regional marine GDP	0.0236
		The ratio of the added value of the marine secondary industry to the regional marine GDP	0.0555
		The ratio of the added value of the marine tertiary industry to the regional marine GDP	0.1036
		Optimization index of marine industrial structure	0.0758
	Marine economic effect	The proportion of the added value of the marine industry to its regional GDP	0.0659
		Elastic coefficient of national marine GDP growth to regional growth	0.0317
	Marine ecological civilization	Exhaust emission per unit GDP	0.1250
		Wastewater discharge per unit GDP	0.1250

Economy green development. In recent years, the level of coordination between marine science and technology innovation and green development of marine economy has been increasing year by year, and is now in a good coordination stage (Wang et al., 2020; Zhao et al., 2022). Third, the impact of marine science and technology innovation on the green development of marine economy. Marine science and technology innovation can promote green development of the local marine economy by promoting the green Total factor productivity of the marine economy (Ning and Song, 2020; Qin and Shen, 2020). Fourth, the efficiency measure of marine science and technology innovation to marine economy green development. The three-stage DEA method shows that the overall efficiency of scientific and technological innovation to the growth of marine economy is not high, and the level of innovation efficiency still has great room for improvement (fan et al., 2019). In the existing research, only the mechanism of marine scientific and technological innovation driving green development of marine economy is analyzed, but no research is conducted on whether regional differences and influencing factors can affect and restrict the green development of marine economy driven by marine scientific and technological innovation. It is necessary to fully discover and understand the influence of these different factors on the green development of marine economy driven by marine scientific and technological innovation, attach importance to marine scientific and technological innovation, optimize the relevant environment and make it play its full role, so as to promote the development of marine economy and achieve all-round progress. As the influence of external conditions does exist, if the impact on the green development of marine economy driven by marine scientific and technological innovation is ignored in future work and the emphasis is put on improving marine scientific and technological innovation, it is likely to run counter to the purpose of promoting the green development of marine economy. In this study, based on panel data, the econometric model is introduced to make an in-depth study on this topic, and the countermeasures and suggestions for optimizing marine scientific and technological innovation to drive the green development of marine economy are discussed.

Data and variable description

The data in this study are from China Ocean Statistics Yearbook (2009–2018), China Statistics Yearbook (2009–2018) and China Financial Yearbook (2009–2018). The main variables are selected as follows:

Explained variables

Green Development of Marine Economy (MEC). Referring to the previous literature results (Li, 2011; Wang, 2013a; Cheng, 2013; Yin, 2013), in view of the availability and comparability of data, the indicator system is this study is mainly constructed from the total marine economy, marine economic structure, marine economic effect and marine ecological civilization, and the weights are determined by using principal component analysis method based on the previous research results (Table 1).

Core explanatory variable

Marine Scientific and Technological Innovation (MST). With reference to previous research results (Yin, 2008; Ni, 2010; Ma, 2012; Jing and Zhang, 2014), the principal component analysis is used in this study to determine the weight based on the previous research results. (Table 2).

Control variable

Opening to the outside world (OPEN)

Referring to the previous research results (Sun and Wan, 2011; Zhang et al., 2013; Dong and Yan, 2015a), in this study, the proportion of the total import and export volume in GDP of each region is used to measure the regional opening up.

TABLE 2 MST evaluation indicator system.

Level 1 indicators	Level 2 indicators	Level 3 indicators	Weights
MST	Basic marine research	Number of marine scientific research institutions	0.0570
		Total number of marine professional and technical personnel	0.0975
		Total number of talents with senior titles	0.0995
		Proportion of professional and technical personnel in marine scientific research institutions with senior professional titles	0.0397
		Total investment of marine scientific research institutions (1,000 yuan)	0.1037
	Marine application research	Number of marine scientific papers published	0.0843
		Number of marine scientific and technological patents accepted	0.0933
		Number of patents granted for marine scientific and technological	0.0955
		Number of marine scientific and technological projects	0.0915
	Marine research and development	Number of achievement application projects	0.0797
		Transformation rate of scientific and technological achievements	0.0176
		Total output value of industrialization of marine scientific and technological achievements	0.0831
		The proportion of the total output value of industrialization of marine scientific and technological achievements to the total output value of marine industry	0.0571

TABLE 3 FD comprehensive indicator system.

Level 1 indicators	Level 2 indicators	Level 3 indicators	Weights
FD	Scale of financial development	Gross output value of financial industry in each province/GDP in each province	0.3560
	Structure of financial development	The proportion of on-the-job personnel in the financial industry to the total employed personnel	0.3211
	Efficiency of financial development	Loan-deposit ratio of financial institutions	0.3229

TABLE 4 Descriptive statistics of main variables.

Variable	Obs	Mean	Std. Dev	Min	Max
MEC	110	5.6268	0.7318	3.6063	6.6164
MST	110	9.2285	2.8631	1.1500	13.1774
OPEN	110	0.0901	0.0606	0.0004	0.2291
FD	110	0.3342	0.0532	0.0616	0.5396
HC	110	11.2074	0.9737	9.5539	13.8637
GI	110	0.5640	0.3561	0.0392	1.6028
TI	110	0.4699	0.0937	0.0493	0.6389

Financial development (FD)

Referring to previous research results (Huang et al., 2014; Yang, 2014; Geng et al., 2015; Xin and Liu, 2015; Zhan and Shan, 2016), in this study, the indicator system is mainly constructed from three aspects: financial development scale, financial development structure and financial development efficiency, and the weight is determined by using principal component analysis based on the previous research results (Table 3).

Human capital (HC)

The level of human capital is directly related to the final result, which can be measured by many methods, but various factors should be fully considered in the selection, such as the availability of data first, because the follow-up research can be completed only if the relevant data are easily obtained, and then the feasibility of operation, which is also the technology for completing the research. In view of the above two factors, the method of Barro and Lee (2000) (Barro and Lee, 2000) is finally determined, that is, it is measured by the years of education of local residents. In this study, the proportion of employed people who are illiterate and semi-literate in China *1.5 + employed people who receive primary education *7.5 + employed people who receive junior high school education *10.5 + employed people who receive high school education *13.5 + employed people who receive junior college or above *17 is adopted.

Government investment (GI)

Referring to the previous research results (Wang, 2013b; Yu and Yang, 2018), in this study, the proportion of science and technology expenditure to GDP is measured by the methods commonly used in most literatures.

Technology input (TI)

Referring to the previous research results (Dong and Yan, 2015b; Sheng and Xu, 2018), in this study, most of the methods commonly used in the literatures are used to measure the proportion of technology transactions in GDP. The descriptive statistics of the mainindicators are shown in Table 4.

Model setup

Basic model setup

Solow model (Lewis, 1996) is the representative of the neoclassical economic growth theory model in the specific form of

$$Y_t = Af(K_t, L_t) \tag{1}$$

$$MEC_{it} = A_{it} MST_{it}^{\alpha} \mathrm{HC}_{it} \tag{2}$$

where,

MEC = green development of marine economy; M.

ST = marine scientific and technological innovation;

A = technical efficiency;

α = output elasticity of marine scientific and technological innovation;

i = the province; t = the year.

Technical efficiency A of green development of marine economy consists of financial development FD, government investment GI and technical input TI, expressed as

$$A_{it} = e^{\phi T_i} \bullet FD_{it}^{\alpha} \bullet GI_{it}^{\beta} \bullet TI_{it}^{\lambda} \tag{3}$$

$$\begin{aligned} \mathrm{In}MEC_{\mathrm{it}} = \gamma_1 \mathrm{In}FD_{it} + \gamma_2 \mathrm{In}GI_{it} + \gamma_3 \mathrm{In}TI_{it} + \gamma_4 \mathrm{In}MST_{it} + \gamma_5 \mathrm{HC}_{\mathrm{it}} + \xi_i \\ + \varepsilon_{it} \end{aligned} \tag{4}$$

Taking the neoclassical economic growth model (Yu and Yang, 2018) as an example, the regression equation is set as follows:

$$\begin{aligned} \mathrm{In}MEC_{\mathrm{it}} = \gamma_0 + \gamma_1 \mathrm{In}FD_{it} + \gamma_2 \mathrm{In}GI_{it} + \gamma_3 \mathrm{In}TI_{it} + \gamma_4 \mathrm{In}MST_{it} \\ + \gamma_5 \mathrm{HC}_{\mathrm{it}} + \xi_i + \varepsilon_{it} \end{aligned} \tag{5}$$

Threshold model setup

$$MEC_{it} = A_{it} MST_{it}^{\alpha} \tag{6}$$

Therefore, with reference to Hansen threshold regression model (Wang and Han, 2017; Xu and Li, 2022), a double-threshold regression model of marine scientific and technological innovation and green development of marine economy is established based on formula (5).

Opening to the outside world as a threshold variable

Technical efficiency A of green development of marine economy consists of financial development FD, human capital HC, government investment GI and technical input TI. Therefore, technical efficiency A can be expressed as:

$$A_{it} = e^{\phi T_i} \bullet FD_{it}^{\lambda_1} \bullet HC_{it}^{\lambda_2} \bullet GI_{it}^{\lambda_3} \bullet TI_{it}^{\lambda_4} \tag{7}$$

$$\begin{aligned} \ln MEC_{it} = {} & \lambda_1 \ln FD_{it} + \lambda_2 \ln HC_{it} + \lambda_3 \ln GI_{it} + \lambda_4 \ln TI_{it} \\ & + \alpha_1 \ln(MST) \bullet I(\ln OPEN \le \theta_1) \\ & + \alpha_2 \ln(MST) \bullet I(\theta_1 < \ln OPEN \le \theta_2) \\ & + \alpha_3 \ln(MST) \bullet I(\ln OPEN > \theta_3) + \phi T + \varepsilon_{it} \end{aligned} \tag{8}$$

Financial development as a threshold variable

Technical efficiency A of green development of marine economy consists of opening to the outside world OPEN, human capital HC, government investment GI and technical input TI. Therefore, technical efficiency A can be expressed as:

$$A_{it} = e^{\phi T_i} \bullet OPEN_{it}^{\lambda_1} \bullet HC_{it}^{\lambda_2} \bullet GI_{it}^{\lambda_3} \bullet TI_{it}^{\lambda_4} \tag{9}$$

$$\begin{aligned} \ln MEC_{it} = {} & \lambda_1 \ln OPEN_{it} + \lambda_2 \ln HC_{it} + \lambda_3 \ln GI_{it} + \lambda_4 \ln TI_{it} \\ & + \alpha_1 \ln(MST) \bullet I(\ln FD \le \sigma_1) \\ & + \alpha_2 \ln(MST) \bullet I(\sigma_1 < \ln FD \le \sigma_2) \\ & + \alpha_3 \ln(MST) \bullet I(\ln FD > \sigma_3) + \phi T + \varepsilon_{it} \end{aligned} \tag{10}$$

Human capital as a threshold variable

Technical efficiency A of green development of marine economy consists of opening to the outside world OPEN, financial development FD, government investment GI and technical input TI. Therefore, technical efficiency A can be expressed as:

$$A_{it} = e^{\phi T_i} \bullet OPEN_{it}^{\lambda_1} \bullet FD_{it}^{\lambda_2} \bullet GI_{it}^{\lambda_3} \bullet TI_{it}^{\lambda_4} \tag{11}$$

$$\begin{aligned} \ln MEC_{it} = {} & \lambda_1 \ln OPEN_{it} + \lambda_2 \ln FD_{it} + \lambda_3 \ln GI_{it} + \lambda_4 \ln TI_{it} \\ & + \alpha_1 \ln(MST) \bullet I(\ln HC \le \sigma_1) \\ & + \alpha_2 \ln(MST) \bullet I(\sigma_1 < \ln HC \le \sigma_2) \\ & + \alpha_3 \ln(MST) \bullet I(\ln HC > \sigma_3) + \phi T + \varepsilon_{it} \end{aligned} \tag{12}$$

Government investment as a threshold variable

Technical efficiency A of green development of marine economy consists of opening to the outside world OPEN, financial development FD, human capital HC and technical input TI. Therefore, technical efficiency A can be expressed as:

$$A_{it} = e^{\phi T_i} \bullet OPEN_{it}^{\lambda_1} \bullet FD_{it}^{\lambda_2} \bullet HC_{it}^{\lambda_3} \bullet TI_{it}^{\lambda_4} \tag{13}$$

$$\begin{aligned} \ln MEC_{it} = {} & \lambda_1 \ln OPEN_{it} + \lambda_2 \ln FD_{it} + \lambda_3 \ln HC_{it} + \lambda_4 \ln TI_{it} \\ & + \alpha_1 \ln(MST) \bullet I(\ln GI \le \sigma_1) \\ & + \alpha_2 \ln(MST) \bullet I(\sigma_1 < \ln GI \le \sigma_2) \\ & + \alpha_3 \ln(MST) \bullet I(\ln GI > \sigma_3) + \phi T + \varepsilon_{it} \end{aligned} \tag{14}$$

Technical input as a threshold variable

Technical efficiency A of green development of marine economy consists of opening to the outside world OPEN, financial development FD, human capital HC and government investment GI. Therefore, technical efficiency A can be expressed as:

$$A_{it} = e^{\phi T_i} \bullet OPEN_{it}^{\lambda_1} \bullet FD_{it}^{\lambda_2} \bullet HC_{it}^{\lambda_3} \bullet GI_{it}^{\lambda_4} \tag{15}$$

$$\begin{aligned} \ln MEC_{it} = {} & \lambda_1 \ln OPEN_{it} + \lambda_2 \ln FD_{it} + \lambda_3 \ln HC_{it} + \lambda_4 \ln GI_{it} \\ & + \alpha_1 \ln(MST) \bullet I(\ln TI \le \sigma_1) \\ & + \alpha_2 \ln(MST) \bullet I(\sigma_1 < \ln TI \le \sigma_2) \\ & + \alpha_3 \ln(MST) \bullet I(\ln TI > \sigma_3) + \phi T + \varepsilon_{it} \end{aligned} \tag{16}$$

Theoretical analysis and research hypotheses

In reality, it is difficult to show a simple linear relationship in the process of marine scientific and technological innovation driving the green development of marine economy in eleven coastal provinces and cities in China, and many factors may have an impact on the driving process, that is, there may be certain "threshold" characteristics in the process of marine scientific and technological innovation driving the green development of marine economy. When the marine scientific and technological innovation ability of the region reaches a certain threshold, the green development of marine economy develops significantly under the influence of factors. Considering that there is little research on the threshold characteristics of marine scientific and technological innovation driving green development of marine economy in the existing literature, this study reviews the relevant literature and finds that the green development of marine economy driven by marine scientific and technological innovation is likely to result from the differences of five factors, i.e., local opening to the outside world, financial development, human capital, government investment and technology investment.

Opening to the outside world

With the continuous acceleration of the process of economic globalization, marine scientific and technological innovation and marine economic development are all affected to varying degrees by the external impact brought by the opening to the outside world, especially when China's marine scientific and technological development starts later than that of western developed countries, some of the marine high-end technological innovation still rely on the replication and transformation of imported technologies. Therefore, the higher the degree of opening to the outside world, the easier it is for all scientific and technological innovation subjects in the industry to come into contact with the world's most cutting-edge and top-notch technologies and products, so as to help each subject better understand the global technology market trends and enhance the effectiveness and timeliness of scientific and technological innovation (Leamer, 1995). At the same time, the improvement of opening to the outside world can effectively accelerate the flow of innovative elements such as domestic marine scientific and technological talents, promote the optimization process of innovative resource allocation (Lai et al., 1995), and further enhance the level of industrial economic development (Wang, 2018). Thus, the following hypothesis is made.

H_1: The degree of opening to the outside world has a positive impact on green development of marine economy driven by marine scientific and technological innovation.

Financial development

The process of marine scientific and technological innovation is a high-investment, high-risk and high-return technological research and development process, which relies on the support of sufficient research and development funding resources in addition to hidden resources such as knowledge and technology. At present, there are three main sources of R&D funds: government investment, investment from innovative subjects such as enterprises, and investment from financial institutions. Compared with the former two kinds of investment, financial institutions have a larger amount of capital investment, which has a more severe impact on the overall innovation process. The researches have shown that new technological innovation needs a large amount of long-term and continuous R&D funding, and it is far from meeting the needs of technological innovation only relying on government special funds investment and innovation subject's own R&D funding support. However, even enterprises with rich innovation resources and huge financial support have external financing in the process of technological innovation. Based on the intervention of financial institutions, enterprises can effectively transfer innovation risks, at the same time, increase R&D capital investment, ensure the continuity and effectiveness of R&D expenditure investment, and further promote innovation efficiency. Thus, the following hypothesis is made:

H_2: Financial development has a positive impact on the green development of marine economy driven by marine high-tech innovation.

Human capital

Human capital, as an indispensable element in marine scientific and technological innovation activities, is also an important foundation for marine economic development, and plays an important driving force in the process of marine economic development driven by marine scientific and technological innovation. In essence, marine scientific and technological innovation activities are the innovation activities of knowledge and foundation, while the main carrier of tacit resources such as knowledge is the talents with knowledge and skills in related fields. Therefore, it can be considered that the investment of human capital is in essence the input of knowledge and technology, as well as the basic elements in scientific and technological innovation activities. The direct influence in the process of technology-driven industrial economic development is reflected in the impact of technological innovation products on economic development. Fundamentally, the scientific and technological innovation products are formed depending on the input of knowledge and technology, that is, the input degree of human capital in the process of marine scientific and technological innovation. Previous studies have proved that the intensity of human capital investment has a direct and significant impact on the process of scientific and technological innovation to promote industrial economic development, and the degree of impact increases with the increase in intensity of human capital investment (Aigner et al., 1977).Thus, the following hypothesis is made.

H_3: Human capital input has a positive impact on the green development of marine economy driven by marine scientific and technological innovation.

Government investment

In the process of marine scientific and technological innovation driving the green development of marine economy, government departments play the role of guiding, promoting and guaranteeing macro-control. First of all, marine scientific and technological innovation activities are the process of effective integration of relevant innovation resources. The flow process of knowledge, technology and R&D funds needs to be carried out under the policy and legal framework, and any resource flow beyond the framework is invalid. In addition, the government's influence on scientific and technological innovation is also reflected in funding. As mentioned above, the current financial support for marine scientific and technological innovation activities mainly comes from three aspects, among which financial investment is one of the important sources of innovation funds. Secondly, the green development of marine economy cannot be separated from the investment and support of government departments. On the one hand, government departments provide goal orientation and

TABLE 5 Panel data, fixed effect and random effect model estimation.

Provinces and cities	Variables	Panel data			Test result
		Ols	Fixed effect	Random effect	
Eleven coastal provinces and cities	MST	0.1681*** (4.55)	0.1221*** (4.81)	0.1294*** (5.27)	Wald test of fixed effect: F (10,92) = 48.32 Huasman test of random effect: chi2(4) = 21.58
	FD	0.0465* (1.87)	0.0642* (1.76)	0.0522* (1.66)	
	HC	0.0420** (1.98)	0.0127* (1.86)	0.0645** (2.16)	
	GI	−0.1687* (−1.81)	0.1304* (1.66)	0.1660* (1.79)	
	TI	0.0185* (1.75)	0.0423** (2.05)	0.0127* (1.66)	
	Coefficient	0.1583*** (3.11)	0.5069*** (6.10)	0.5713*** (5.66)	
	R^2	0.6832	0.6955	0.6242	
Circum-Bohai Sea Economic Zone	MST	0.4192*** (5.53)	0.3609* (1.85)	0.1491*** (3.42)	Wald test of fixed effect: F (3,29) = 37.42 Huasman test of random effect: chi2 (4) = 43.66
	FD	0.1470 (0.78)	0.0391* (1.71)	0.1592 (0.55)	
	HC	0.1294* (1.77)	0.0106* (1.68)	0.0619 (0.98)	
	GI	−0.3027*** (−3.32)	0.3016*** (3.23)	0.2172*** (3.04)	
	TI	0.0103* (1.66)	0.1065* (1.72)	0.0101 (1.32)	
	Coefficient	0.3316** (2.31)	0.4383*** (3.66)	0.4587*** (3.84)	
	R^2	0.6186	0.6596	0.6015	
Yangtze River Delta Economic Zone	MST	0.6485** (2.15)	0.1413*** (3.14)	0.3465* (1.69)	Wald test of fixed effect: F (4, 39) = 47.42 Huasman test of random effect: chi2 (4) = 51.36
	FD	0.0633* (1.74)	0.0646 (0.37)	0.0363* (1.67)	
	HC	0.1021* (1.64)	0.0474* (1.70)	0.1821* (1.90)	
	GI	−0.2212** (−2.14)	0.2591* (2.25)	0.2424* (2.20)	
	TI	0.0641** (2.14)	0.1990* (1.90)	0.0447* (1.68)	
	Coefficient	0.4521* (1.93)	0.4371* (1.81)	0.4472* (1.83)	
	R^2	0.6320	0.6822	0.6105	
Pearl River Delta Economic Zone	MST	0.2006** (2.64)	0.0975* (2.17)	0.2620** (2.44)	Wald test of fixed effect: F (3, 20) = 20.42 Huasman test of random effect: chi2 (4) = 16.48
	FD	0.0569** (2.14)	0.0656** (2.37)	0.0616** (2.21)	
	HC	0.1659** (2.39)	0.0573** (2.31)	0.1251** (2.10)	
	GI	−0.1845** (2.26)	0.2860** (2.60)	−0.0875* (2.09)	
	TI	0.0652** (2.37)	0.1266** (2.12)	0.0544** (2.27)	
	Coefficient	0.5872*** (4.87)	0.4308*** (3.65)	0.4231*** (3.44)	
	R^2	0.6413	0.6609	0.6302	

overall planning for the green development of the marine economy, and promote all economies in the marine industry to move forward in the direction of government planning through policy input, project establishment and other means, and strive to promote the green development of the marine economy. At the same time, the market's own mediation ability can no longer meet the needs of green development of marine economy due to the complex effect of the green development of marine economy and its variability, so it is necessary to rely on the government's macro-control ability to maintain the steady, rapid and high development of marine economy. On the other hand, government investment can effectively ensure the steady progress of green development of marine economy, and provide a healthy external environment guarantee for green development of marine economy through policies, regulations and other measures. Thus, the following hypothesis is made.

H_4: Government investment has a positive impact on the green development of marine economy driven by marine scientific and technological innovation.

Technical input

The intensity of technical input is one of the important indicators to measure the level of investment in marine scientific and technological innovation resources. Generally speaking, the higher the intensity of technical investment, the stronger the innovation ability of marine science and technology, and the more obvious its driving effect on the green development of marine economy. Relevant studies have shown that green development of marine economy driven by scientific and technological innovation is largely affected by the intensity of technical input. The different intensity of technical input leads to significant differences in the effect of green development of marine economy driven by scientific and technological innovation in different regions. The stronger the intensity of technical input, the stronger the driving ability, and the more obvious the result. Thus, the following hypothesis is made.

H_5: The intensity of technical input has a positive impact on the green development of marine economy driven by marine scientific and technological innovation.

Empirical analysis

Model results and analysis

According to Table 5, among the estimation results of OLS, fixed effect and random effect models in eleven coastal provinces and cities of China and Circum-Bohai Sea Economic Zone, Yangtze River Delta Economic Zone and Pearl River Delta Economic Zone divided by marine economic belt, Wald F test value of fixed effect and LM test value of random effect model show that the original hypothesis of OLS should be rejected and alternative hypothesis of fixed effect and random effect model should be accepted.

The test results in Table 5 show that according to R^2, the fitting degree of fixed effect of panel model is the best among the three models, followed by OLS method of panel data. Since the possible "pseudo-regression" problem of the series is not considered in the OLS method for panel data, the fixed-effect model is selected as the optimal one in terms of volume test and economic significance.

By analyzing the panel data of green development of marine economy driven by marine scientific and technological innovation in 11 coastal provinces and cities from 2008 to 2017, the regression equation is obtained as follows:

$$\begin{aligned}\mathrm{In}MEC_{it} &= 0.5069 + 0.0642\mathrm{In}FD_{it} + 0.1304\mathrm{In}GI_{it} + 0.0423\mathrm{In}TI_{it} \\ &\quad + 0.1221\mathrm{In}MST_{it} + 0.0127\mathrm{HC}_{\mathrm{it}}\end{aligned} \tag{17}$$

Equation 17 shows that in the whole regression model, government investment contributes the most to the high-quality development of marine economy, with a coefficient of 0.1304, followed by marine scientific and technological innovation, with an action coefficient of 0.1221 and a technology input coefficient of 0.0423, which is slightly higher than the contribution of human capital. The regression model accords with the hypothesis of neoclassical economic growth model and the current situation of marine economic development. Firstly, the neoclassical economic growth model holds that labor and capital can be replaced each other under perfect competition. With the development of science and technology, the contribution of single labor force to economy is far less than the force of science and technology to economic development. Furthermore, with the continuous development of the Internet and artificial intelligence, the functions of science and technology products are constantly being improved and gradually developing in the direction of replacing human resources. The model has shown that the contribution of technical input to the high-quality development of marine economy is greater than that of human capital, so the model is considered reasonable. Secondly, as far as the current situation of marine economic development is concerned, the development of marine economy mostly depends on the guidance of the government that the government fundamentally affects the development priorities of various industries of marine economy by adjusting the policies and the direction of capital investment, so as to further improve the quality of marine economic development. From the perspective of marine science and technology, most marine scientific and technological projects come from the government, so it can be considered that the government plays an essential role in promoting the development of marine science and technology. In the model, the strong collinearity of government investment to the high-quality development of marine economy has been shown. In conclusion, the model is reasonable.

According to the division of marine economic regions, the regression equation is divided into "Circum-Bohai Sea Economic Zone," "Yangtze River Delta Economic Zone" and "Pearl River Delta Economic Zone" for analysis one by one.

(1) Regression model for Circum-Bohai Sea Economic Zone

$$\begin{aligned}\mathrm{In}MEC_{it} &= 0.4383 + 0.0391\mathrm{In}FD_{it} + 0.3016\mathrm{In}GI_{it} + 0.1065\mathrm{In}TI_{it} \\ &\quad + 0.3609\mathrm{In}MST_{it} + 0.0106\mathrm{HC}_{\mathrm{it}}\end{aligned} \tag{18}$$

(2) Regression model for Yangtze River Delta Economic Zone

$$\begin{aligned}\mathrm{In}MEC_{it} &= 0.4371 + 0.0646\mathrm{In}FD_{it} + 0.2591\mathrm{In}GI_{it} + 0.1990\mathrm{In}TI_{it} \\ &\quad + 0.1413\mathrm{In}MST_{it} + 0.0474\mathrm{HC}_{\mathrm{it}}\end{aligned} \tag{19}$$

(3) Regression model for the Pearl River Delta Economic Zone

$$\begin{aligned}\mathrm{In}MEC_{it} &= 0.4308 + 0.0656\mathrm{In}FD_{it} + 0.2860\mathrm{In}GI_{it} + 0.1266\mathrm{In}TI_{it} \\ &\quad + 0.0975\mathrm{In}MST_{it} + 0.0573\mathrm{HC}_{\mathrm{it}}\end{aligned} \tag{20}$$

The comparison of the regression models of "three major economic zones" shows that the coefficients of each influencing factor in different regression models have little change, and the results are the same as those of the coastal zone model as a whole. Among them, the financial development and human capital in the Pearl River Delta region contribute more to the high-quality development of marine economy than other regions, reflecting two major characteristics: First, the Pearl River Delta Economic Zone has a better financial financing environment. Considering that Shenzhen and Guangzhou have a good foundation for financial development, they can communicate and cooperate with a wider range of financial institutions in the operation of the marine economy, thus enhancing the contribution of financial development to the high-quality development of the marine economy; Secondly, marine aquaculture, tourism and other

TABLE 6 Self-sampling test results of threshold effect of each threshold variable.

Threshold variables	Threshold types	F	p	Times of BS	Critical value			Threshold value	95% confidence interval
					1%	5%	10%		
Opening to the outside world	Single threshold	9.868*	0.092	300	16.799	10.741	7.338	0.54	[0.500,0.793]
	Double threshold	10.622	0.174	200	39.479	15.041	11.047		
	Triple threshold	−20.425	0.864	200	10.487	1.784	−3.518		
Government investment	Single threshold	13.471**	0.02	300	17.314	12.692	9.298	0.562	[0.559,0.572]
	Double threshold	19.7	0.155	200	50.361	37.973	30.106	0.979	[0.832,1.127]
	Triple threshold	0	0.2	200	0	0	0		
Financial development	Single threshold	15.537***	0.005	300	13.049	9.352	7.029	0.574	[0.532,0.618]
	Double threshold	23.449**	0.037	200	24.150	22.436	16.544	0.812	[0.804,0.859]
	Triple threshold	0	0.194	200	0	0	0		
Human capital	Single threshold	13.524***	0.003	300	12.068	10.828	8.808	0.534	[0.518,0.614]
	Double threshold	20.308**	0.048	200	23.234	18.732	16.557	0.743	[0.707,0.753]
	Triple threshold	0	0.227	200	0	0	0		
Technical input	Single threshold	13.613	0.242	300	21.033	18.425	15.311	0.322	[0.293,0.459]
	Double threshold	16.108	0.312	200	32.059	21.283	19.753	0.744	[0.685,0.753]
	Triple threshold	0	0.3	200	0	0	0		

industries in the Pearl River Delta Economic Zone are relatively developed, both of which need a lot of human resources as support. Therefore, the influence of human capital in this region is higher than that in other regions.

Compared with other regions, the Yangtze River Delta Economic Zone has a technical input that plays a more prominent role in the high-quality development of the marine economy, because it covers economically developed regions such as Shanghai and Zhejiang, and has a more active technology trading market, which can provide richer technical support for the development of the marine industry. Considering that the coefficient of marine scientific and technological innovation is lower than the regional technical input, it is believed that the science and technology that promotes the high-quality development of marine economy in the region mainly comes from the regional technology exchange market, rather than the regional marine scientific and technological innovation itself.

Equation 18 shows that the government investment and the contribution of marine scientific and technological innovation in the Circum-Bohai Sea Economic Zone are far greater than those in other regions. As mentioned above, the development of China's marine economy relies heavily on the government, which, while investing in policies, regulations and funds, tends to promote the development of the industrial economy by enhancing the industry's own scientific and technological innovation capabilities. This region not only contains the political center of our country, but also has a large number of marine scientific research institutions and marine economic research institutes, so the government investment and marine scientific and technological innovation in this region contribute more to the high-quality development of marine economy than other regions.

Factor analysis

Test of threshold effect

Threshold effect of marine scientific and technological innovation on marine economic growth is tested with opening to the outside world as the threshold variable. The threshold self-sampling tests are carried out under the assumptions of single threshold, double threshold and triple threshold respectively. In order to judge the threshold model to be selected, the F statistical value and the p-value obtained by Bootstrap method are used.

Table 6 shows the obtained results. The above-mentioned influencing factors are classified on this basis: factors with a significant threshold including two influencing factors of marine human capital and opening to the outside world, and factors with a double threshold including government investment and financial development. However, the above results are not available for the impact of technical input, and the threshold effect has not been detected. Whether the effect of productive force driven by development in science and technology will change due to this has not been determined yet, which needs further analysis.

Estimation and analysis of threshold model

It is necessary to carry out regression test on samples with different threshold intervals. On the basis of the results obtained above, various factors are investigated to determine their impact on marine scientific and technological innovation, whether the latter can drive the development of marine economy, and the role played therein and the subsequent degree of impact are interfered by various factors. Through analysis, different impacts generated by these factors are determined, so as to grasp their importance in

TABLE 7 Regression results of threshold model for each threshold variable.

	OPEN single	GI single	FD double	HC double
lgOPEN		0.0256* (1.84)	0.0185* (1.76)	0.0175* (1.66)
lgGI	0.0758** (2.24)		0.0386** (2.46)	0.0524** (2.14)
lgFD	0.0628* (1.87)	0.0424** (1.75)		0.0485* (1.66)
lgTI	0.0463* (1.82)	0.0498* (1.69)	0.0236* (1.77)	0.0442* (1.75)
lgHC	0.0370** (2.04)	0.0246** (2.27)	0.0329* (1.87)	
lgMST1	0.6433** (2.25)	0.6577** (2.37)	0.6121** (2.28)	0.6322** (2.45)
lgMST2	1.2332*** (3.12)	1.0423*** (2.66)	0.4892** (2.35)	1.0794*** (3.14)
LgMST3			0.5624** (2.30)	1.0974*** (3.34)
Constant	0.4748*** (4.88)	0.3451** (2.17)	\0.4537** (2.24)	0.3228** (2.15)
R^2	0.602	0.426	0.413	0.431

different threshold intervals and grasp their function characteristics. The test results are shown in Table 7.

Table 7 shows the results of threshold regression, indicating the changes of different threshold intervals. The action force of science and technology input presents different change characteristics here, which can be used to formulate accurate marine strategies and implement better policies for marine scientific and technological innovation to drive green development of marine economy. Specifically, there is a single threshold value of 0.54 for opening to the outside world (OPEN). When OPEN<0.54, the effect of marine scientific and technological innovation on the green development of marine economy is 0.6433, indicating that in this threshold interval, the green development of marine economy will be raised by 0.6433 for every 1% increase in marine scientific and technological innovation, and when opening to the outside world exceeds the threshold value, i.e., OPEN>0.54, the coefficient value is 1.2332, indicating that the improvement of opening to the outside world is beneficial to the exertion of marine science and technology. Thus, both of them change positively and play a positive role in promoting.

There is a single threshold value for the government investment (OPEN). When GI < 0.562, the effect of marine scientific and technological innovation on the green development of marine economy is 0.6577, indicating that in this threshold interval, the green development of marine economy will be raised by 0.6577 for every 1% increase in marine scientific and technological innovation. However, when the government investment exceeds the threshold value and GI > 0.562, the above coefficient value is 1.0423, which is obviously improved and changed compared with the original situation, indicating that the improvement of government investment is beneficial to the exertion of marine science and technology, and the two change positively and play a positive role in promoting.

Judging from two factors with double thresholds, there are two obvious thresholds for financial development (FD), which are 0.574 and 0.812 respectively. When the financial development is less than 0.574, the force coefficient of marine scientific and technological innovation driving the green development of marine economy is 0.6121, while when the financial development is 0.574 ≤ FD < 0.812, it decreases to 0.4892, when FD > 0.812, it rises greatly to 0.5624. Therefore, from the overall trend, the role of marine scientific and technological innovation in driving the green development of the marine economy is also on the rise with the increase in financial development, i.e., financial development is an important force for marine scientific and technological innovation to drive the green development of the marine economy, and plays a key role therein with positive effects. From the intermediate stage, the role of marine marine scientific and technological innovation in driving the green development of marine economy is slightly reduced, possibly because financial development and marine marine scientific and technological innovation are synchronized to a certain extent, and can grow together in some stages. The analysis of some samples from coastal provinces and cities shows that financial development can play a positive role in marine marine scientific and technological innovation and produce crowding-out effect.

The threshold value of human capital (HC) is 0.534 and 0.743, which constitute three intervals. The contribution coefficients of marine marine scientific and technological innovation to the green development of marine economy are 0.6322, 1.0794 and 1.0974, respectively, which clearly shows that human capital has played a positive role in this period and effectively promoted the effect of marine marine scientific and technological innovation. The capital invested by HC is positively related to the final force, which can effectively promote the marine marine scientific and technological innovation elements to play a role. This result suggests that there is a shortage of marine scientific and technological talents from the current domestic situation, which seriously restricts the application and popularization of marine science and technology, and marine scientific and technological talents are an important prerequisite for the green development of marine economy.

Conclusion

In this study, the panel data of eleven coastal provinces and cities in China from 2008 to 2017 are tested empirically, and the following conclusions are drawn:

With reference to previous literature (Chen and Ma, 2020; Cu, 2020; Wang et al., 2020; Wang et al., 2021; Zhao et al., 2022), according to the constructed neoclassical growth model that marine scientific and technological innovation driving the green development of marine economy, marine scientific and technological development and green development of marine economy are positively correlated on the whole, and all input variables promote economic development but with certain differences. Among them, government investment and marine scientific and technological innovation play the most prominent role in promoting the green development of marine economy, while the sharing degree of human capital is the weakest, reflecting that China's marine economy is now in the stage where science and technology gradually replace labor, which conforms to the development law of marine science and technology and marine economy in China. Based on the analysis of the growth models of "Circum-Bohai Sea Economic Zone," "Yangtze River Delta

Economic Zone" and "Pearl River Delta Economic Zone," at present, the promotion of science and technology to economic development in each marine economic zone is obvious, and the promotion of green development of regional marine economy varies by various input variables, which reflects that each economic zone fully considers its own regional characteristics and effectively allocates resources for different marine industry types in the process of enhancing marine scientific and technological innovation capability and promoting green development of marine economy (Ning and Song, 2020; Qin and Shen, 2020).

With reference to previous literature (Wang and Han, 2017), by building a panel threshold model, the five factors, namely opening to the outside world, government investment, financial development, human capital and technical input are examined, which contribute to the green development of marine economy driven by marine scientific and technological innovation. According to the empirical results, it is concluded that all kinds of external influencing factors will interfere with the role of marine scientific and technological innovation by means of promotion or restriction. The test results can be classified according to the threshold characteristics, including three factors: first, factors with significant thresholds, including opening to the outside world and government investment; second, factors with double thresholds, including financial development and human capital; third, technical input without thresholds. Thus it is proved that this result is closely related to many factors and is the result of their joint action. The role of marine scientific and technological innovation is affected by external factors under certain conditions with different forces for the green development of the marine economy, which hence should be fully taken into account when formulating the marine scientific and technological strategy and in the implementation of the policies (Aigner et al., 1977; Lai et al., 1995; Leamer, 1995; Wang, 2018).

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

Author contributions

FW and FC are responsible for outlining and writing, TL is responsible for data processing.

Funding

This work was supported by the Major Projects of National Social Science Foundation of China (Grant No. 21&ZD100).

Conflict of interest

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

Publisher's note

References

Aigner, D., Lovell, C. A. K., and Schmidt, P. (1977). Formulation and estimation of stochastic frontier production function models. *J. Econ.* 6 (1), 21–37. doi:10.1016/0304-4076(77)90052-5[J]

Barro, R. J., and Lee, J. W. (2000). *International data on educational attainment updates and implications*. Cambridge, MA, USA: National Bureau of Economic Research, Inc.[C].

Chen, Z. W., and Ma, L. (2020). Research on spatial pattern and spatial effect of marine science and technology innovation efficiency in China's coastal provinces. *J. Coast. Res.* 115 (115), 42–45. doi:10.2112/jcr-si115-013.1[J]

Cheng, Na (2013). *Marine economic development in China from the perspective of sustainable development*. Doctoral Dissertation (Changchun, China: School of Economics, Jilin University).

Cu, S. S. (2020). Effects of corporate governance on R&D investment in marine technology enterprises. *J. Coast. Res.* (110), 167–170.[J].

Dong, Lihong, and Yan, Taihua (2015). Technological input, opening to the outside world and "curse of resources": Looking at terms of trade from China's provincial panel data. *J. Int. Trade* (09), 55–65.[J].

Dong, Lihong, and Yan, Taihua (2015). Technological input, opening to the outside world and "curse of resources": Looking at terms of trade from China's provincial panel data. *J. Int. Trade* (09), 55–65.[J].

fan, Wu, Gao, Qiang, and Liu, Tao (2019). Efficiency Measure of marine science and technology innovation to marine economic growth. *Statistics decision-making* 35 (23), 119–122.[J].

Geng, Chen, Liu, Xing, and Xin, Qingquan (2015). Credit discrimination, financial development and term structure of borrowing by private enterprise banks. *Account. Res.* (04), 40–46.[J].

Huang, Jianhuan, Lyu, Hailong, and Wang, Liangjian (2014). The mechanism of financial development affecting regional green development --- based on the research of ecological efficiency and spatial measurement. *Geogr. Res.* 33 (03), 532–545.[J].

Jing, Weimin, and Zhang, Lu (2014). Environmental regulation, opening to the outside world and green technology progress in Chinese industry. *Econ. Res.* 49 (09), 34–47.[J].

Lai, Mingyong, Xu, Helian, and Bao, Qun (1995). *Export trade and economic growth*. Shanghai, China: Shanghai Sanlian Bookstore.

Leamer, E. A. (1995). *Trade economist's view of U.S. Wage and globalization. Semnar paper*. Storrs, South Yorkshire: Department of Agricultural and Resorce Economics University of Connection.

Lewis, Arthur. (1996). *Economic growth theory*. Beijing, China: Commercial Press.[M].

Li, Bin (2011). *Comparative study on regional marine economic development in China from the perspective of resources and environment*. Doctoral Dissertation (Qingdao, China: School of Economics, Ocean University of China).

Ma, Jishan (2012). *Regional marine scientific and technological innovation and interactive development of blue economy based on a case study of qingdao city*. Doctoral Dissertation (Qingdao, China: School of Economics, Ocean University of China).

Ni, Guojiang (2010). *Strategic research on marine scientific and technological innovation in China based on marine sustainable development*. Doctoral Dissertation (Qingdao, China: School of Management, Ocean University of China).

Ning, Ling, and Song, Zeming (2020). The dynamic relationship between marine science and technology innovation, marine total factor productivity and marine economic development: An empirical analysis based on panel vector autoregression. *Sci. Technol. Manag. Res.* 40 (6), 164–170.[J].

Qin, Lingui, and Shen, Tiyan (2020). Is scientific and technological innovation contributing to the high-quality development of the Chinese marine economy: An empirical test based on the impact of scientific and technological innovation on the green total factor productivity of the marine economy. *Adv. Countermeas. Sci. Technol.* 37 (9), 105–112.[J].

Sheng, Yuhua, and Xu, Yingchao (2018). Inertia of technology investment and enterprise performance based on a case study of the listed manufacturing enterprises. *Sci. Technol. Prog. Policy* 35 (18), 105–112.[J].

Sun, Yongqiang, and Wan, Yulin (2011). Financial development, opening to the outside world and income gap between urban and rural residents - empirical analysis based on provincial panel data from 1978 to 2008. *Financial Res.* (01), 28–39.[J].

Wang, Bo, and Han, Limin (2017). The influence of the change of marine industrial structure on the growth of marine economy in China: A regression analysis based on the panel threshold effect of 11 coastal provinces and cities. *Resour. Sci.* 39 (6), 1182–1193.[J].

Wang, Chunjuan, Liu, Dahai, and Wang, Xixi (2020). Study on the measurement of the harmonious relationship between national ocean innovation capability and ocean economy. *Adv. Countermeas. Sci. Technol.* 37 (14), 39–46.[J].

Wang, Guangsheng (2013). *Empirical study on the relationship between economic growth and marine environmental pollution in coastal areas of China*. Doctoral Dissertation (Qingdao, China: School of Economics, Ocean University of China).

Wang, Jueshuai (2018). Threshold effect of opening to the outside world and economic growth in provinces of China. *Mod. Econ. Sci.* 9, (01), 55–61.[J].

Wang, J. Y., Shi, X., and Du, Y. W. (2021). Exploring the relationship among marine science and technology innovation, marine finance, and marine higher education using a coupling analysis: A case study of China's coastal areas. *Mar. Policy* 132 (132), 104706. doi:10.1016/j.marpol.2021.104706[J].

Wang, Yebin (2013). Comparison of technological innovation effects of government investment and financial credit --- empirical study based on high-tech industry. *Collect. Essays Finance Econ.* (3), 3–8.[J].

Xin, Yi, and Liu, Fengliang (2015). Financial development, technological innovation and industrial structure transition - theoretical analysis framework of multidisciplinary endogenous growth. *Manag. World* (10), 24–39.[J].

Xu, Jianing, and Li, Weidong (2022). The impact of the digital economy on innovation: New evidence from panel threshold model. *Sustainability* 14 (22), 15028. doi:10.3390/su142215028[J].

Yang, Youcai (2014). Financial development and economic growth - analysis based on threshold variables of financial development in China. *Financial Res.* (2), 59–71.[J].

Yin, Kedong (2013). *Comprehensive strength assessment of strong marine provinces (municipalities) in coastal areas of China*. Beijing, China: People's Press.[M].

Yin, Kedong (2008). *Index system of marine power*. Beijing, China: Economic Science Press.[M].

Yu, Jingtao, and Yang, Dali (2018). Government investment, economic freedom and innovation efficiency: Empirical experience from 24 leading countries. *China Soft Sci.* (07), 181–192.[J].

Zhan, Yong, and Shan, Li (2016). Financial development, marine scientific and technological innovation and smart city construction - analysis from the perspective of informatization development. *Financial Res.* (02), 4–15.[J].

Zhang, Chengsi, Zhu, Yuetong, and Lu, Zhe (2013). The mystery of restraining effect of opening to the outside world on financial development. *Financial Res.* (06), 16–30.[J].

Zhao, Wei, Lee, Wei, and Zhai, Renxiang (2022). Study on the coupling and coordinated development of the coastal areas financial development, scientific and technological innovation and marine economic system. *J. Nanjing Univ. Aeronautics Astronautics Sci. Soc. Sci.* 24 (1), 30–36.[J].