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Impact of Environmental Regulation on Coastal Marine Pollution—A Case of Coastal Prefecture-Level Cities in China

Jintao Ma[1], *Qiuguang Hu*[1,2*] *and Xinyi Wei*[1]

[1] *School of Business, Ningbo University, Ningbo, China,* [2] *Marine Economic Research Center, Dong Hai Strategic Research Institute, Ningbo University, Ningbo, China*

Based on the data on the level of environmental regulation and the degree of coastal marine pollution in 46 coastal prefecture-level cities in China from 2004 to 2016, this study uses the mediation effect model and the spatial Durbin model to analyze the impact and role of environmental regulation on offshore pollution from multiple dimensions and mechanisms. The findings are as follows: (1) Environmental regulation has an inverted "U"-shaped nonlinear effect on coastal marine pollution, which first intensifies and then inhibits. (2) Promoting green technology innovation is an important mechanism for environmental regulation to improve the quality of the marine environment, and the impact of environmental regulation on green technology innovation is characterized by a "U" shape. (3) Environmental regulation of coastal cities can affect coastal marine pollution in adjacent areas through spatial spillover effects, and the impact trajectory also shows an inverted "U"-shaped curve. This study proposes that in the process of marine environ-mental governance, first, a scientific and strict environmental regulation system should be constructed, and differentiated environmental regulation policies should be implemented. Second, giving full play to the conduction effect of green technology innovation and promoting the research and development, diffusion, and application of green technology are necessary. Third, we must attach importance to the cross-regional transfer and control of offshore pollution and promote regional joint prevention and control work.

Keywords: environmental regulation, coastal marine pollution, green technology innovation, spatial measurement, marine environmental protection

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Correspondence:
Qiuguang Hu
huqiuguang@nbu.edu.cn

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1 INTRODUCTION

In order to achieve sustainable marine ecological environment and promote the stable development of China's marine economy, China's coastal cities bear the heavy burden of marine pollution prevention and control. Since the reform and opening up, China's eastern coastal cities, such as Shanghai and Shenzhen, have developed rapidly. However, the long-term use of extensive economic model has exacerbated the generation and discharge of pollutants. Although the level of pollution treatment technology has gradually improved, due to insufficient technology accumulation and excessive reliance on the self-purification ability of the ocean, land-based pollution with long duration, complexity, and concealment has caused great damage to the marine environment. To curb the deterioration of the ecological environment, the coastal city governments has implemented a series of positive measures. For example, Shanghai has established a marine ecological red line management system, and Shenzhen has improved the marine environmental management mechanism of land-sea coordination. After their long-term efforts, marine environmental protection has achieved phased results. The sea area with water quality worse than Grade IV has dropped significantly. Nevertheless, according to the Bulletin on the State of China's Marine Ecological Environment, the pollution of some sea areas such as the East China Sea is still serious; the direct discharge of pollutants, such as chemical oxygen demand, petroleum, and heavy metals is still high; and the prevention and control of marine pollution undertaken by coastal cities remain arduous. Moreover, due to the strong cross-border flow characteristics of coastal marine pollution and the existence of "Pollution Haven" effect, isolated environmental regulation hardly plays its expected role, and the implementation effect of relevant policies will be influenced by adjacent coastal cities. The " race to the bottom" and "incomplete implementation" of environmental regulation not only aggravate local marine pollution but also restrict the overall governance of marine environment (Zhang et al., 2021; Hu and Ma, 2022). Therefore, analyzing the impact of environmental regulation on coastal marine pollution at the urban level, exploring its action mechanism, emphasizing the direction for follow-up marine environmental protection work, promoting the improvement of marine ecological environment quality, and accelerating the construction of marine ecological civilization are necessary.

Owing to the great differences in research samples, index data, and research perspectives, three main views on the relationship between environmental regulation and environmental pollution exist. (1) Environmental regulation helps reduce environmental pollution. Most relevant literature starts from the "Porter hypothesis," indicating that the strong level of environmental regulation will force enterprises to conduct scientific research innovation and industrial upgrading to realize decoupling between economic development and environmental pollution (Xia and Zhong, 2016; Hui and Zhao, 2017; Sun and Zaenhaer, 2021). On the basis of the perspective of the implementation of industrial policies for environmental protection, Jiang (Jiang and Cui, 2019) found that environmental regulation will guide enterprises to increase environmental protection investment and jointly promote environmental protection and economic development. Wu (Wu and Han, 2020) stated that improving the level of environmental regulation will promote green technology innovation and help improve the ecological environment. Some studies were extended on this basis. Zhang (2017) focused on the externality of policies and emphasized that cooperative governance between cities is the key to giving play to the effectiveness of environmental regulation and improving environmental quality. (2) Environmental regulation is inconducive to reducing environmental pollution. Some scholars have recommended the "green paradox" (Sinn, 2008) and believed that strict environmental regulation fails to effectively promote the improvement of ecological environment quality. That is, with the enhancement of environmental regulation, the production and operation cost of enterprises will increase significantly. When the expected cost increases, enterprises may speed up the exploitation and consumption of resources and increase the emission of pollutants in the short term (Zhang, 2014; Li et al., 2018). In addition, "follow-the-cost effect" may occur. Enterprises will accelerate the release of production capacity to compensate for the increase in cost and follow the development model of "pollution first, treatment later" (Qi and Wang, 2015; Fünfgelt and Schulze, 2016; Xu, 2016), which will aggravate the problem of environmental pollution. Some studies have also performed analyses on the basis of the "Pollution Haven effect," indicating that the improvement of environmental regulation will cause nearby transfer of pollution, resulting in the transfer of polluting industries from areas with high level of environmental regulation to areas with low level (Wu et al., 2017; Shen et al., 2017; Qin and Ge, 2018). In the absence of overall coordination, the environmental regulation policies formulated by cities to achieve local environmental improvement will not be conducive to the overall governance of the ecological environment. (3) The impact of environmental regulation on environmental pollution is uncertain. Many studies have emphasized that a nonlinear relationship exists between the two. For example, Zhang (Zhang and Wei, 2014) believed that the effect of environmental regulation will change from a "green paradox" effect to a "forced emission reduction" effect with the increase in its intensity. Zhou (Zhou et al., 2015) found that low-level environmental regulation will accelerate the consumption of fossil energy. Only after crossing the "threshold" can the energy-saving effect of environmental regulation be brought into play. Moreover, great differences in the impact of different types of environmental regulation tools on the ecological environment exist (Ban and Liu, 2021), and no unified conclusion on which is stronger or weaker between market- and command-based tools has been drawn (Li and Zhang, 2020; Wang and Lu, 2021). Existing research on the spatial effect of environmental regulation also has some differences. Ji (Ji and Song, 2021) regarded the cities in the Yangtze River Delta as a sample and found that the environmental regulation of adjacent cities will aggravate the pollution agglomeration of local cities. Sun (Sun and Zaenhaer, 2021) used the data of national prefecture-level cities to conduct an empirical study and believed that the implementation of environmental regulation will help reduce the level of environmental pollution in adjacent cities.

To sum up, studies have conducted extensive and in-depth discussions on the impact mechanism and transmission path between environmental regulation and environmental pollution. Based on the perspectives of different industries and regions, the theories such as "Porter Hypothesis" and "Following Cost

Theory" are demonstrated in detail. But studies focused on terrestrial pollution, research in the marine field remains lacking. China's academic research in the field of marine ecological environment started in the 1960s, but the progress was slow. After entering the 21st century, with the country's increasing emphasis on marine ecology, related research has ushered in vigorous development (Li et al., 2011; Gao and Gao, 2012; Peng et al., 2018). However, because the statistical standards have not been perfected, marine-related data are still lacking. Existing literature often makes empirical analysis by using coastal provincial data; discusses the impact of environmental regulation on marine economic development, industrial structure, and scientific and technological innovation (Zhao, 2019; Ge et al., 2020; Xu and Lin, 2020; Chen, 2021); or focuses on the influencing factors of coastal marine environment to test the relationship among marine economic growth (Wang et al., 2019), urbanization promotion (Yu et al., 2020), economic growth goal (Shen et al., 2021), and coastal marine pollution. Few studies have analyzed the impact mechanism of environmental regulation on coastal marine pollution on the basis of the data of coastal prefecture-level cities, and research results on the spillover effect of environmental regulation on coastal marine pollution in adjacent areas from a spatial perspective are lacking. Thus, the innovation of this study lies in the following: (1) sink the research object to coastal prefecture-level cities, avoid the deviation of results due to insufficient samples and wide content, fully consider the objective differences within a province, accurately evaluate the impact of environmental regulation on coastal marine pollution, and analyze the action mechanism of environmental regulation on coastal marine environmental pollution from the perspective of green technology innovation; (2) integrate the spatial spillover effect into the research scope, analyze the impact of local environmental regulation on coastal marine pollution in adjacent areas, and comprehensively evaluate the effectiveness of environmental regulation in controlling coastal marine environmental pollution to provide a reference basis for marine ecological environment governance.

2 RESEARCH HYPOTHESES

This study focuses on the coastal marine ecological environment, and discusses the impact of environmental regulation on coastal marine pollution and its mechanism. Based on the environmental Kuznets curve theory (Gene and Alan, 1995), Porter hypothesis (Porter and van der Linde, 1995), and environmental regulation competition theory (Arik, 2003), the corresponding research hypotheses are put forward on the basis of analyzing its influence mechanism, which lays a solid foundation for empirical analysis.

2.1 Nonlinear Characteristics of the Impact of Environmental Regulation

Environmental regulation is an important measure to deal with the negative externality of environmental pollution. The government restricts the production and operation activities of enterprises through administrative punishment, pollutant discharge permit, and pollutant discharge tax, which aims to internalize the environmental cost, guide enterprises to adjust the development mode, and reduce the discharge of wastewater and waste gas and the demand for fossil energy to realize ecological protection and sustainable development. However, in accordance with the environmental Kuznets curve (Gene and Alan, 1995), a nonlinear relationship may exist between environmental regulation and coastal marine pollution. When the level of environmental regulation is low, facing the constraints of environmental regulation, enterprises may choose to reduce scientific research investment, accelerate the release of production capacity, increase pollutant emissions, and compensate for the increased production costs to maximize their own interests, resulting in the intensification of land-based pollution and further deterioration of the marine ecological environment. Nonetheless, with the strengthening of environmental regulation, on the one hand, small enterprises with backward production capacity and serious pollution will hardly bear the rising pollution cost and be gradually eliminated in the market competition. On the other hand, to increase market share and realize long-term benefits, some large-scale enterprises will promote the innovation of production and pollution control technology by optimizing resource allocation and increasing scientific research investment, which will improve urban production efficiency and reduce pollution emissions. From the above discussion, Hypothesis 1 is proposed as follows.Hypothesis 1 (H1). *The impact trajectory of environmental regulation on coastal marine pollution shows an inverted "U" curve.*

2.2 Mechanism of Environmental Regulation

The impact of environmental regulation on green technology innovation is the result of the game between "innovation compensation effect" and "follow-the-cost effect." Improving the level of environmental regulation, on the one hand, will increase the cost of pollution control and emission reduction of enterprises, cause an overall decline in enterprise business performance in the short term, squeeze its investment in scientific and technological research and development (R&D). In particular, small- and medium-sized enterprises with low awareness of environmental protection and shortage of funds and talents often avoid the R&D of green technologies with large investment and high risk. On the other hand, according to Porter hypothesis, the benefits of technological innovation will be significantly higher than the increased environmental costs in the long run. To achieve long-term and stable development, enterprises with a certain foundation in terms of talents, funds, and equipment have the ability and power to carry out green technology innovation and offset the rising cost caused by environmental regulation through improving economic efficiency, promoting pollution reduction, and optimizing resource allocation. Therefore, this study infers that the impact of environmental regulation on green technology innovation has nonlinear characteristics. The improvement of green technology innovation level is conducive to the improvement of marine ecological environment governance. Studies have shown that 80% of the total amount of marine pollutants comes from land-based pollution, which shows that curbing the discharge of land-based pollution into the sea is an important task to protect the coastal marine environment. Green technology innovation with green development as the core will promote the energy saving and cleaning of enterprise production equipment, technology, and products; accelerate the optimization and upgrading of industrial structure in coastal cities; and reduce land-based pollution from the source, including reducing the direct discharge of sewage into the sea, lowering excessive factors, such as ammonia nitrogen. From the above discussion, Hypothesis 2 is proposed as follows.Hypothesis 2 (H2). *Environmental regulation has an impact on coastal marine pollution through green technology innovation.*

2.3 Spatial Spillover Effect of Environmental Regulation

Coastal marine pollution has strong cross-border flow characteristics, which can break through the spatial constraints and spread to adjacent areas with the help of natural factors, such as ocean current and wind direction. At the same time, enterprises, as the main body of pollutant emission, will also carry out cross land transfer. Therefore, the marine environmental quality of coastal cities is closely related to the spatial adjacent areas. The environmental regulation in these areas will have an impact on the coastal marine pollution in the adjacent areas. The governments of coastal cities restrict the production and operation of enterprises by controlling the total amount of emissions, raising emission standards, and strengthening rewards and punishments to strengthen the remediation of land-based pollution. On the one hand, due to the "bottom-by-bottom competition" and "incomplete implementation" of environmental regulation, to reduce the cost of environmental treatment, some polluting enterprises may relocate and move to adjacent areas with relatively loose environmental regulation to transfer the pollution nearby and form the "Pollution Haven" effect (Shen et al., 2017; Wu and He, 2017), resulting in the deterioration of the ecological environment in adjacent areas. On the other hand, in the long run, environmental regulation will stimulate the enthusiasm of enterprises for green innovation. To improve market competitiveness, enterprises will actively innovate production and environmental protection technologies, which will effectively curb the transfer and diffusion of pollution and strengthen the benign interaction between regions. From the above discussion, Hypothesis 3 is proposed as follows. Hypothesis 3 (H3). *The environmental regulation of coastal cities can affect the coastal marine pollution in adjacent areas through the spatial spillover effect.*

3 METHODOLOGY AND DATA

3.1 Dependent Variable

Existing studies generally use indicators, such as industrial wastewater discharge (He and Chen, 2018) and nonclass water quality and sea area (Zhang et al., 2020), to measure the degree of coastal marine pollution. Although they reflect the coastal marine pollution to a certain extent, the relevant data are relatively general and one-sided and do not sink to the level of coastal cities to reflect the specific changes in coastal marine pollution. In this study, the average concentration data of inorganic nitrogen, active phosphate, petroleum, and chemical oxygen demand were obtained by identifying the histogram of the main exceeding standard factors in the coastal waters of coastal cities in the Bulletin on Environmental Quality of China's Coastal Seas (Yu et al., 2020; Shen et al., 2021). After dimensionless processing of the data, the coastal marine pollution index was constructed by the entropy method, as shown in Equation (1):

$$MP_i = a_1 DIN_i + a_2 PO_i + a_3 OIL_i + a_4 COD_i \tag{1}$$

where MP is the coastal marine pollution index, DIN is inorganic nitrogen, PO is active phosphate, OIL is petroleum, and COD is the chemical oxygen demand. a_1, a_2, a_3, and a_4 are the weights of each index. According to the Bulletin of Marine Ecology and Environment Status of China, we evaluated the degree of impact on the marine ecological environment by measuring the average point exceeding rate of each factor during the sample period, and set the corresponding weights based on the exceeding conditions, $a_1 = 0.6$, $a_2 = 0.3$, $a_3 = 0.07$, and $a_4 = 0.03$.

3.2 Explanatory Variable

Due to the multi-dimensional nature of environmental regulation and the low availability of relevant data, there is a certain controversy about the measurement of environmental regulation level. Four main methods can be used to measure the level of regional environmental regulation. First, on the basis of the micro level, the intensity of environmental regulation is reflected by the pollution costs of enterprises, such as sewage charges and governance investment (Xie et al., 2014; Chen et al., 2021; Liu and Wan, 2021). Second, the regulation level is evaluated through government pollution control investment (Song and Wang, 2013; Yang and Wen, 2021). Third, a comprehensive index of environmental regulation is established on the basis of the discharge of various pollutants (Ye et al., 2018; Wu et al., 2021). Fourth, the number of environmental protection regulations and the frequency of environmental words in a government work report are used (Chen et al., 2018; Wang, 2018 Zhang and Chen, 2021). Considering the objectivity of indicators and the availability, based on the above analysis, we referred to the research of Shen (Shen et al., 2017), Li (Li and Du, 2014), and selected four single indicators: removal rate of industrial sulfur dioxide, removal rate of industrial smoke, comprehensive utilization rate of industrial solid waste, and sewage treatment rate. We determined the weight of each index by using the improved entropy method and calculated the comprehensive index of environmental regulation to reflect the intensity of environmental regulation level. The specific steps are as follows.

(1)We performed dimensionless processing on the indicator, and shifted the indicator data so that it is concentrated between

30-100. i represents the year, j represents the indicator type, x_{ij}^{*} is the standardized index, x_{ij} is the initial indicator, $x_{max(j)}$ and $x_{min(j)}$ represent the maximum and minimum values of the j index in all cities in the current year, respectively

$$x_{ij}^{*} = \frac{x_{ij} - x_{min(j)}}{x_{max(j)} - x_{min(j)}} * 70 + 30 \tag{2}$$

(2) We calculated the proportion (D_{ij}) of x_{ij}^{*}, the entropy value (k_j) of the j and the difference coefficient (f_j). The larger the difference coefficient (f_j), the more important x_{ij} is in the comprehensive evaluation, and then the weight N_j is determined

$$D_{ij} = \frac{x_{ij}^{*}}{\sum_{i=1}^{n} x_{ij}^{*}},$$
$$k_j = -\left(\frac{1}{lnn}\right)\sum_{i=1}^{n} D_{ij} \ln D_{ij},$$
$$f_j = 1 - k_j \tag{3}$$

$$N_j = \frac{f_j}{\sum_{m=1}^{m} f_j} = \frac{1 - k_j}{\sum_{j=1}^{m}(1 - k_j)} \,(0 \le N_j \le 1) \tag{4}$$

(3) We calculated comprehensive indicators of environmental regulation. The larger the comprehensive index of environmental regulation (ers_i), the higher the level of environmental regulation.

$$ers_i = \sum_{j=1}^{m} (N_j * 100) * (D_{ij} * 100) \tag{5}$$

3.3. Control Variable

With reference to existing research, the control variables included the following: (1) Economic development (lnpergdp). The development of regional economy has promoted the improvement of living standards and raised the public's requirements for the quality of ecological environment. The government and enterprises have implemented positive measures to respond to social needs. We chose the logarithm of per capita GDP to measure the economic development level of a city. (2) Industrial structure (ind). The industrial structure of a city has a profound impact on the decision-making behavior of the local government. We used the proportion of secondary industry to evaluate the level of urban industrial structure. (3) Foreign capital utilization (fdigdp). The effective utilization of foreign capital has played an important role in enterprise transformation and upgrading, scientific research, development, and utilization. We reflected the utilization of foreign capital by the proportion of actually used foreign capital in GDP. (4) Urbanization level (urban). Urbanization is a complex process that promotes the evolution of social and economic structure. In this process, the various changes in the economy, population, and society of coastal cities will exert an impact on the marine ecological environment. We characterized this index by urbanization rate. (5) Population density (rapopul). A high population density promotes economies of scale and industrial division of labor, as well as intensifies the generation and emission of pollutants. We measured it by the population per square kilometer of a city. (6) Level of marine economic development (reocean). The level of marine economic development can reflect the local attention to marine resources and environment. Considering that coastal cities do not publish the total marine production value, we replaced it with the total marine production value of coastal provinces and reflected this index by the proportion of total marine production value in regional production value. Summary statistics for the data are shown in **Table 1**.

3.4. Data Sources and Model Settings

3.4.1. Data Sources

We regarded the panel data of 46 coastal prefecture-level cities in China from 2004 to 2016 as a sample to evaluate the impact of environmental regulation on coastal marine pollution. The time span has been selected for the following reasons. Firstly, the Bulletin on Environmental Quality of China's Coastal Seas and the Bulletin on the State of China's Marine Environment were merged into the Bulletin on the State of China's Marine Ecological Environment after 2017, and the pollutant concentration is no longer reported in the combined bulletin. Secondly, the serious lack of data before 2004 has forced us to consider this time span. The study includes all coastal cities in China, but the data of some coastal cities are seriously missing (such as Danzhou City) which had to be overlooked. Finally, 46 coastal prefecture-level cities are selected out of the 57 coastal prefecture-level cities in China as the research samples. The data related to the construction of a coastal marine pollution index came from the Bulletin on Environmental Quality of China's Coastal Seas[1]. The index data for evaluating the level of environmental regulation and control variable data came from the statistical yearbooks of China's cities, China's environment, China's oceans, and coastal cities and provinces[2].

3.4.2. Model Settings

To test the above hypotheses, we referred to the research of Li (Li and Zhang, 2020), Yu (Yu et al., 2020) and Wu (Wu et al., 2021), built a model on the basis of the nonlinear impact of environmental regulation on coastal marine environmental pollution. The model was constructed as

$$lnmp_{it} = \alpha_0 + \alpha_1 lners_{it} + \alpha_2 (lners)_{it}^2 + \alpha_3 \sum control_{it} + \gamma_t + \lambda_i + \xi_{it} \tag{6}$$

where $lnmp$ is the logarithm of the coastal marine pollution index; $lners$ and $(lners)^2$ are the logarithm of the environmental regulation level and its square term, respectively; $control$ is the control variable; γ_t and λ_i control the fixed effects of time and city, respectively; ξ_{it} is a random interference item; i represents the city; and t represents the year.

[1] Relevant information is obtained by querying the official website of the Ministry of Ecology and Environment of the People's Republic of China.

[2] The statistical yearbook data is obtained by querying EPS database.

TABLE 1 | Summary statistics.

Variables	Variable Definition	Mean	SD	Min	Max
mp	Coastal marine pollution index	0.1555	0.1175	0.0204	0.9242
ers	Environmental regulation level	16.7224	1.9766	8.5160	19.9844
lnpergdp	Logarithm of GDP per capita	10.5449	0.6876	8.5431	13.0557
ind	Proportion of secondary industry to GDP	0.4969	0.0880	0.1857	0.8228
fdigdp	Proportion of foreign capital to GDP	0.0343	0.0452	0.0003	0.5755
urban	Urbanization rate	0.5533	0.1672	0.1123	1.0000
rapopul	Population per square kilometer	6.4158	4.7057	0.4435	34.5354
reocean	Proportion of marine production output to GDP	0.1610	0.0634	0.0524	0.3763

4 EMPIRICAL RESULTS

4.1 Benchmark Estimation Results

In accordance with the benchmark model, this study quantitatively evaluated the relationship between environmental regulation and coastal marine pollution. In order to test whether the influence of the core explanatory variables is robust and improve the stability of the test results, we conducted regression analysis by sequentially increasing the control variables. The empirical results are shown in **Table 2**, where column (1) refers to the regression results without control variables, and columns (2–7) are the regression results with sequentially increasing control variables. In column (1), the primary term coefficient of the core explanatory variable environmental regulation level (lners) is positive, and the square term coefficient is negative. After the control variables are added in turn, the results have not changed significantly. This finding shows that the impact of environmental regulation on coastal marine pollution has the characteristic of inverted "U." The low level of environmental regulation in coastal cities intensifies the problem of coastal marine pollution. With the improvement of the level of environmental regulation, its containment effect on pollution becomes gradually prominent, and Hypothesis 1 is verified. We explain the above results as follows: when the level of environmental regulation is low, although the emission and technical standards formulated by the government increase the environmental cost of enterprises, due to the insufficient punishment of pollution behavior and the limited policy coverage, enterprises are more inclined to increasing product output and pollution emission, especially when environmental regulation is expected to become gradually stricter. In addition, to avoid environmental governance responsibilities, polluting enterprises in areas with strong environmental regulation may choose to migrate across land, making areas with weak environmental regulation "Pollution Haven" However, with the improvement of the level of environmental regulation, some enterprises with high energy consumption, excessive pollution, and low production capacity will hardly bear the rising environmental costs and be gradually eliminated in the market competition. At the same time, enterprises with certain advantages

TABLE 2 | Benchmark estimation results.

Variables	Dependent Variable: Coastal Marine Pollution Index						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
lners	1.986**	2.130**	2.359***	3.360***	3.793***	3.783***	4.012***
	(0.831)	(0.792)	(0.704)	(0.734)	(0.668)	(0.664)	(0.691)
$(\text{lners})^2$	-0.354**	-0.367**	-0.407**	-0.597***	-0.675***	-0.673***	-0.718***
	(0.158)	(0.150)	(0.134)	(0.137)	(0.124)	(0.122)	(0.128)
lnpergdp		-0.229***	-0.199***	-0.196***	-0.174***	-0.176***	-0.179***
		(0.050)	(0.059)	(0.061)	(0.050)	(0.049)	(0.050)
ind			-0.227	-0.235	-0.281*	-0.280*	-0.326**
			(0.139)	(0.135)	(0.136)	(0.136)	(0.129)
fdigdp				-0.610***	-0.619***	-0.618***	-0.594***
				(0.099)	(0.103)	(0.103)	(0.093)
urban					-0.434***	-0.438***	-0.327***
					(0.085)	(0.080)	(0.066)
rapopul						-0.001	-0.002
						(0.003)	(0.002)
reocean							1.615
							(1.146)
_cons	-5.229***	-3.251***	-3.765***	-5.080***	-5.654***	-5.616***	-6.127***
	(1.097)	(0.970)	(0.900)	(0.790)	(0.700)	(0.684)	(0.762)
Time fixed effect	YES	YES	YES	YES	YES	YES	YES
Urban fixed effect	YES	YES	YES	YES	YES	YES	YES
N	598	598	598	598	598	598	598
Adj R2	0.478	0.483	0.494	0.507	0.527	0.536	0.543

*Figures in () are robust standard error; ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.*

in capital, talents, and technology will actively increase R&D investment, promote green technology innovation, and accelerate the application and diffusion of energy-saving and environmental protection technologies to improve market competitiveness and achieve long-term and stable development. In this process, land-based pollution emissions are significantly reduced, marine environmental quality is improved, and the inhibitory effect of environmental regulation on coastal marine pollution is effectively brought into play.

Among the control variables, the coefficient of economic development (lnpergdp) is significantly negative, indicating that the improvement of economic development level will inhibit coastal marine pollution. With the vigorous development of economy, the enthusiasm of the public to participate in environmental governance has gradually increased. The demand for high-quality development will promote the implementation of ecological protection, effectively restrict the production behavior of enterprises, and then reduce the pollution of marine environment. The coefficient of industrial structure (ind) is significantly negative, implying that the increase in the proportion of secondary industry contributes to the reduction in coastal marine pollution. The reason may be that the eastern coastal cities are basically in the late stage of industrialization, that is, the stage of technology intensification. Cities pay attention to the cultivation of high-tech, high-added-value, and low-pollution industries and emphasize innovation and green development. The negative coefficient of foreign capital utilization (fdigdp) is significant, indicating that the effective utilization of foreign capital promotes marine environmental governance, possibly because the inflow of foreign capital helps alleviate the capital constraints of enterprises and increase the investment in environmental protection and green innovation. At the same time, the entry of foreign capital is accompanied by the exchange of knowledge and technology. Through learning advanced environmental protection concepts and management experience, the level of environmental governance will be significantly improved. The coefficient of urbanization level (urban) is significantly negative, demonstrating that the promotion of urbanization has a positive impact on the marine ecological environment, which may be due to the following two aspects. First, the improvement of urbanization level will promote the rational allocation of resources and enhance the efficiency of ecological environment treatment. Second, the promotion of urbanization will contribute to the R&D, application, and diffusion of green technology and encourage cleaner production and end of pipe treatment.

4.2 Robustness Test

To ensure that the regression results accurately reflect the impact of environmental regulation on coastal marine pollution, a robustness test was performed by eliminating sample extreme values and interference samples and replacing core explanatory variables. The specific results are shown in **Table 3**. First, to avoid the impact of sample extreme values on the empirical results, we shrank the tail of the sample by 5%. In column (1), the primary term coefficient of environmental regulation level (lners) is positive, and the secondary term coefficient is negative, which is consistent with the benchmark results. Second, we considered that Shanghai and Tianjin, as municipalities directly under the central government, have higher administrative levels than others and may be subject to greater constraints in terms of economy and environment. Therefore, after excluding Shanghai and Tianjin from the sample, we reassessed the regression results. The regression results in column (2) have not changed significantly. Lastly, referring to the studies of Wu (Wu and Han, 2020), Shen (Shen et al., 2017), and Ye (Ye et al., 2018), we built a comprehensive index of environmental regulation on the basis of the emission and removal rate of various pollutants in cities and tested the robustness by replacing explanatory variables. In accordance with columns (3) and (4), the primary term coefficients of environmental regulation level (er, erh) are significantly positive, and the square term coefficients are significantly negative. The above tests verify the robustness of the benchmark regression results, indicating that the impact trajectory of environmental regulation on coastal marine pollution presents an inverted "U" curve.

4.3 Endogenous Test

A two-way causal relationship may exist between environmental regulation and coastal marine pollution, and endogenous problems will cause errors in the regression results. Therefore, to ensure the reliability of benchmark analysis, we referred to existing studies (Liu and Wan, 2021; Zhang and Chen, 2021) and conducted an endogenous test through lag regression and instrumental variable regression. The specific results are shown in **Table 4**. We regarded the level of environmental regulation lagging behind the first period (l.lners) as the explanatory variable for regression. In accordance with column (1), the primary term coefficient of the index is significantly positive, and the square term coefficient is significantly negative. This result indicates that

TABLE 3 | Robustness test.

Variables	Tail shrinking	Exclude Municipalities	Replace explanatory variables	
	(1)	(2)	(3)	(4)
lners	2.717***	4.174***		
	(0.759)	(0.857)		
$(\text{lners})^2$	-0.502***	-0.751**		
	(0.140)	(0.160)		
er			0.039**	
			(0.017)	
$(\text{er})^2$			-0.001**	
			(0.001)	
erh				0.074**
				(0.041)
$(\text{erh})^2$				-0.015**
				(0.007)
Control	YES	YES	YES	YES
Time fixed effect	YES	YES	YES	YES
Urban fixed effect	YES	YES	YES	YES
N	538	572	598	598
Adj R2	0.467	0.532	0.457	0.439

*Figures in () are robust standard error; ***, ** indicate significance at the 1%, 5% levels, respectively.*

the impact of environmental regulation on coastal marine pollution presents an inverted "U" shape, which proves the robustness of the benchmark results. On this basis, to further eliminate the endogenous impact, we regarded the first and second lag terms of environmental regulation level (lners) as instrumental variables. From column (2), when the instrumental variables meet the statistical requirements, no significant difference exists between the sign and significance of the primary term and square term coefficients of the environmental regulation level (lners) and the benchmark results, which confirms the robustness of the previous conclusions.

4.4 Mechanism Analysis

The internalization of enterprise pollution costs by environmental regulation may lead to capital crowding out effect and inhibit the improvement of green technology innovation level. However, in order to maximize profits, enterprises may increase capital investment in green R&D, so as to improve production efficiency and the innovation effect. Compared with traditional technological innovation, green technological innovation pays more attention to resource protection and pollution control. Its high-efficiency production mode is conducive to energy conservation, emission reduction and cleaner production, curb the damage of land-based pollution to the coastal marine environment. Therefore, it is necessary to further explore the impact mechanism of environmental regulation on coastal marine pollution from the perspective of green innovation. We referred to the "Porter hypothesis" and regarded green technology innovation as an intermediary variable to test whether environmental regulation has an impact on coastal marine pollution through affecting green technology innovation (Wu and Han, 2020; Wu et al., 2021). The mediation effect model was constructed as

$$innov_{it} = \beta_0 + \beta_1 lners_{it} + \beta_2 (lners)_{it}^2 + \beta_3 \sum control_{it} + \gamma_t + \lambda_i + \xi_{it} \quad (7)$$

$$lnmp_{it} = \nu_0 + \nu_1 innov_{it} + \nu_2 lners_{it} + \nu_3 (lners)_{it}^2 + \nu_4 \sum control_{it} + \gamma_t + \lambda_i + \xi_{it} \quad (8)$$

where *innov* is the level of green technology innovation, which is represented by the total number of green patent applications in a city in a year. The relevant data were obtained by querying the State Patent Office. The interpretation of other variables is the same as that in model (6). If the coefficients β_1, β_2, and ν_1 are significant, then an intermediary effect exists.

The regression results are shown in **Table 5**. In column (1), the primary term coefficient of environmental regulation level (lners) is negative, and the square term coefficient is positive. This result demonstrates that the impact of environmental regulation on urban green technology innovation is "U" shaped, which first inhibits and then promotes. In column (2), the coefficient of green innovation level (innov) is significantly negative, indicating that improving the green innovation level of coastal cities helps reduce coastal marine pollution. Therefore, Hypothesis 2 is verified. Environmental regulation exerts an impact on coastal marine pollution through affecting green technology innovation. In the absence of external constraints, enterprises often ignore the damage to the ecological environment in the processes of production and operation and lack the enthusiasm to increase investment in green scientific research and promote cleaner production. Hence, the government should urge enterprises to bear environmental social responsibility through environmental regulation. However, when the level of environmental regulation is relatively low, the "innovation compensation effect" hardly covers the "follow-the-cost effect." Enterprises tend to avoid green technology innovation and follow the traditional development model. Nevertheless, with the improvement of environmental regulation intensity, increased pollution emission costs will urge enterprises to adjust their development strategies. To avoid being eliminated from the market or

TABLE 4 | Endogenous test.

Variables	Lag regression	Instrumental variable regression
	(1)	(2)
l.lners	1.722**	
	(0.681)	
l. (lners)^2	-0.309**	
	(0.129)	
lners		25.177**
		(12.362)
(lners)^2		-4.543**
		(2.235)
Control	43S	YES
Time fixed effect	YES	YES
Urban fixed effect	YES	YES
N	552	495
LM-statistics		36.222
F-statistics		14.211
χ2 P-value		0.468
Adj R2	0.286	0.029

*Figures in () are robust standard error; ** indicates significance at the, 5% level, respectively.*

TABLE 5 | Mechanism analysis.

Variables	innov	lnmp
	(1)	(2)
lners	-32.952***	3.683***
	(6.443)	(0.613)
(lners)^2	5.804***	-0.652***
	(1.194)	(0.114)
innov		-0.006**
		(0.002)
Control	YES	YES
Time fixed effect	YES	YES
Urban fixed effect	YES	YES
N	598	598
Adj R2	0.447	0.547

*Figures in () are robust standard error; ***, ** indicate significance at the 1%, 5% levels, respectively.*

migrating outward, enterprises will pay considerable attention to the R&D and application of green technology; actively develop or introduce green technology by fully considering R&D capacity and economic benefits, promote energy conservation, emission reduction, and cleaner production.

4.5 Spatial Regression Results

4.5.1 Spatial Correlation Test

To analyze whether environmental regulation has a spatial spillover effect on coastal marine pollution, we should test the spatial autocorrelation of the coastal marine pollution index. This study identified the spatial correlation of coastal marine pollution in 46 coastal cities from 2004 to 2016 through Moran's I index. The specific results are shown in **Table 6**. **Table 6** presents that the Moran's I index for coastal marine pollution is significantly positive, except for individual years. This result indicates that a significant spatial positive correlation in the degree of coastal marine pollution exists among China's coastal cities, with evident spatial agglomeration characteristics. This finding lays a theoretical foundation for this study to further explore the impact mechanism of environmental regulation on coastal marine pollution by using a spatial econometric model.

4.5.2 Spatial Model Settings

To accurately evaluate the spatial effect of environmental regulation and avoid influencing the effectiveness of the conclusion due to setting errors, we conducted an identification test on the spatial panel model. The specific test types and results are shown in **Table 7**. First, LM and robust LM were used to test the spatial lag and correlation. The test results show that the model has spatial lag and error terms. On this basis, the appropriate spatial econometric model was selected through LR and Wald tests. Both of them pass the 1% significance test, which implies that choosing the spatial Dobbin model (SDM) for demonstration is more reasonable. Lastly, the Hausman test shows that the result is significant at the level of 1%. Therefore, we chose the fixed effect model of SDM to analyze the spatial effect of environmental regulation on coastal marine pollution. The model was constructed as

$$lnmp_{it} = \rho_0 + \rho_1 lners_{it} + \rho_2 (lners)^2_{it} + \rho_3 \sum controlit + \delta Wlnmp_{it} + \theta_1 Wlners_{it} + \theta_2 W(lners)^2_{it} + \theta_3 W \sum control_{it} + \gamma t + \lambda_i + \xi_{it} \quad (9)$$

where δ is the spatial autoregressive coefficient of coastal marine pollution, W is the spatial weight matrix, ρ is the coefficient of the explanatory variable, θ is the coefficient of the spatial interaction term of the explanatory variable, and the interpretation of other variables is the same as that in model (6). The spatial weight matrix selected in this study is the geographical distance weight matrix, which is expressed by the reciprocal of the linear distance between the centers of two regions.

4.5.3 Spatial Correlation Test

We used SDM to test the spatial spillover effect of environmental regulation on coastal marine pollution. The regression results are shown in **Table 8**. From column (1), under the geographical distance matrix, the spatial autoregressive coefficient of coastal marine pollution is significantly positive, the spatial interaction coefficient of the primary term of environmental regulation level (lners) is significantly positive, and the spatial interaction coefficient of the square term is significantly negative. This result shows that the coastal marine pollution of coastal cities not only has an endogenous interaction effect but also has an exogenous interaction effect of environmental regulation. Hypothesis 3 is verified. Environmental regulation can affect coastal marine pollution in adjacent areas through the spatial spillover effect, and the impact trajectory shows an inverted "U" curve. We proposed the following three reasons. First, differences in the implementation of environmental regulations exist among various coastal cities. Under the dual pressure of local finance and promotion championship, " race to the bottom " and "incomplete implementation" of environmental regulation may occur. Polluting enterprises that cannot adapt to the local strict environmental regulation will migrate to the adjacent areas with relatively loose regulation, thus aggravating the marine pollution problem of adjacent coastal cities. Second, because of the spatial spillover of coastal marine pollution itself, with the improvement of environmental regulation level, the quality of marine ecological environment in a region will gradually improve. The emission reduction and pollution control effect brought by environmental regulation will spread to adjacent areas to reduce the coastal marine pollution of adjacent coastal cities. Third, the positive influence of regional interaction effect has been brought into play. Environmental regulation in a region has brought "demonstration effect" and "warning effect" to the governments and enterprises in adjacent regions. At the same time, with the

TABLE 6 | Moran's I index of coastal marine pollution in coastal cities.

Year	Moran's I	p-value	Year	Moran's I	p-value
2004	0.064	0.151	2011	0.236	0.001
2005	0.178	0.009	2012	0.196	0.004
2006	0.171	0.010	2013	0.158	0.015
2007	0.194	0.004	2014	0.173	0.009
2008	0.155	0.016	2015	0.107	0.059
2009	0.240	0.001	2016	0.104	0.062
2010	0.236	0.001			

TABLE 7 | LM, Wald, LR and Hausman Tests.

Type	Z	p-value
Lagrange multiplier (error)	69.629	0.000
Robust Lagrange multiplier (error)	31.981	0.000
Lagrange multiplier (lag)	43.793	0.000
Robust Lagrange multiplier (lag)	6.145	0.013
LR spatial lag	33.04	0.000
LR spatial error	33.06	0.000
Waldspatial lag	21.25	0.003
Waldspatial error	20.88	0.007
Hausman	58.38	0.000

TABLE 8 | Regression results of spatial dobbin model.

Variables	Dependent Variable: Coastal Marine Pollution Index		
	(1)	(2)	(3)
lners	4.793**		
	(2.336)		
$(lners)^2$	-0.863**		
	(0.436)		
W×lners	37.637***		
	(13.477)		
$W\times(lners)^2$	-7.037***		
	(2.482)		
erh		0.103**	
		(0.059)	
$(erh)^2$		-0.017**	
		(0.008)	
W×erh		0.563***	
		(0.208)	
$W\times(erh)^2$		-0.058**	
		(0.028)	
er			0.084**
			(0.035)
$(er)^2$			-0.003**
			(0.001)
W×er			0.364**
			(0.150)
$W\times(er)^2$			-0.014**
			(0.006)
rho	0.229***	0.467***	0.223***
	(0.086)	(0.068)	(0.089)
sigma2_e	0.055***	0.057***	0.055***
	(0.003)	(0.003)	(0.003)
Control	YES	YES	YES
N	598	598	598
Adj R2	0.098	0.109	0.091

*Figures in () are robust standard error; ***, ** indicate significance at the 1%, 5% levels, respectively.*

continuous improvement of the state's attention to ecological and environmental protection, the diffusion and application of green technologies, such as pollution control and cleaner production, will also be accelerated.

To verify the reliability of the results of spatial spillover effect, we tested the robustness by replacing explanatory variables. In columns (2) and (3), the spatial autoregressive coefficients are significantly positive, Hand the spatial interaction term coefficients of the primary term and square term of environmental regulation level (er, erh) are significantly positive and negative, respectively, which is basically consistent with the previous conclusions. Therefore, the test results of environmental regulation on the spatial spillover effect of coastal marine pollution have strong robustness. On this basis, we decomposed the spatial effect to deeply explore the impact of environmental regulation on coastal marine pollution in a region and adjacent areas and explained it through direct and indirect effects. In accordance with **Table 9**, the indirect effect of environmental regulation on coastal marine pollution is significant, which is similar to the impact track of local effect and shows the dynamic characteristic of inverted "U." The indirect effect is significantly greater than the direct effect, which further shows that in geographical space, adjacent

TABLE 9 | Spatial effect decomposition.

Variables	Direct Effect	Indirect Effect	Total Effect
lners	4.053**	26.750**	30.803***
	(0.061)	(11.125)	(11.168)
$(lners)^2$	-0.726**	-5.021**	-5.748***
	(0.438)	(2.040)	(2.048)
erh	0.130**	1.122***	1.252***
	(0.061)	(0.363)	(0.384)
$(erh)^2$	-0.020**	-0.121**	-0.141**
	(0.008)	(0.048)	(0.050)
er	0.090**	0.473***	0.563***
	(0.035)	(0.180)	(0.186)
$(er)^2$	-0.003**	-0.018***	-0.021***
	(0.001)	(0.007)	(0.007)

*Figures in () are robust standard error; ***, ** indicate significance at the 1%, 5% level, respectively.*

coastal cities will jointly bear the pollution of coastal marine environment and enjoy the results of environmental governance.

5 DISCUSSION

Improving the governance level and the quality of marine ecological environment is crucial for the development of China's marine cause. After long-term efforts, China's marine environmental protection has achieved phased results (Guan et al., 2019; Li, 2020; Chen and Hu, 2021). However, the pollution of some sea areas is still serious, the marine ecological situation remains severe, and the green paradox and pollution transfer phenomenon exist to a certain extent. The implementation effect and impact mechanism of environmental regulation policies in coastal cities should be analyzed. On the basis of the panel data of 46 coastal prefecture-level cities in China, we explored the impact of environmental regulation on coastal marine pollution from a multidimensional perspective. Definition of symbols in formulas are shown in **Table 10**. Our research contributes to the literature in two important aspects. (1) Existing research on the relationship between environmental regulation and environmental pollution mainly focuses on inland areas, and research focusing on the marine field is lacking. Most of the studies stay at the provincial level, without fully considering the objective differences between coastal cities in economic level, industrial structure, and innovation factors. We sank the analysis object to coastal prefecture-level cities and

TABLE 10 | Nomenclatures.

Symbol used	Definition of the symbol
α	coefficient of variable
β	coefficient of variable
ν	coefficient of variable
ρ	coefficient of variable
γ	fixed effects of time
λ	fixed effects of city
ξ	random interference item
θ	coefficient of the spatial interaction term
δ	spatial autoregressive coefficient
W	spatial weight matrix

quantitatively evaluated the impact of environmental regulation on coastal marine pollution by constructing environmental regulation level indicators and marine pollution indexes. The finding shows that environmental regulation has an inverted "U" effect on coastal marine pollution, which first intensifies and then inhibits. Therefore, coastal cities should improve environmental regulation. While eliminating high-pollution and inefficient industries, the government should force enterprises to independently develop or introduce green technologies to effectively promote cleaner production, energy conservation, and emission reduction. On this basis, we analyzed the mechanism of environmental regulation from the perspective of green technology innovation and found that promoting green technology innovation is an important mechanism for environmental regulation to improve the quality of marine environment. (2) Studies on the effectiveness of environmental regulation in ecological governance are often limited to the direct effect of environmental regulation. Few studies have explored the impact of environmental regulation on the coastal marine environment of surrounding cities from a spatial perspective. In accordance with the geographical distance weight matrix, we used SDM to test the spatial spillover effect of environmental regulation on coastal marine pollution. We found that the coastal marine pollution of coastal cities has not only an endogenous interaction effect but also an exogenous interaction effect of environmental regulation. The indirect effect of environmental regulation on coastal marine pollution is significant and presents the same inverted "U" effect as that of the local one. Thus, the effective implementation of environmental regulation should be based on regional joint prevention and control. Strengthening communication and cooperation and coordinating environmental regulation actions by coastal city governments are important contents to promote the continuous improvement of marine ecological environment quality.

6 CONCLUSIONS

This study used the panel data of 46 coastal prefecture-level cities in China from 2004 to 2016 as samples to quantitatively evaluate the relationship between environmental regulation and coastal marine pollution and explored its role from the perspective of green technology innovation. On this basis, the spatial spillover effect was included in the research scope, and the impact mechanism of environmental regulation on coastal marine pollution was deeply analyzed. We reached the following conclusions: (1) The impact of environmental regulation on coastal marine pollution shows an inverted "U" shape. The low level of environmental regulation in coastal cities intensifies the problem of coastal marine pollution. With the improvement of the level of environmental regulation, its containment effect on coastal marine pollution becomes gradually prominent. (2) Environmental regulation exerts an impact on coastal marine pollution through affecting green technology innovation. When the level of environmental regulation is relatively low, the "innovation compensation effect" hardly covers the "follow-the-cost effect." However, with the improvement of the intensity of environmental regulation, the enthusiasm of enterprises for green technology innovation will gradually increase to promote marine ecological environment protection. (3) The environmental regulation of coastal cities can affect the coastal marine pollution in adjacent areas through the spatial spillover effect. The impact trajectory also shows an inverted "U" curve, and the indirect effect is significantly greater than the direct effect. The adjacent coastal cities share the responsibility of marine pollution and the results of marine governance.

The above conclusions have important implications for controlling land-based pollution emissions and improving marine ecological environment governance:

1. Build a scientific and strict environmental regulation system. Coastal city governments should accurately understand the role of environmental regulation in marine ecological environment protection and implement differentiated environmental regulation policies with comprehensive consideration of regional development level, geographical location, and pollution status. The central government should strengthen environmental protection supervision, enhance the performance evaluation system guided by green transformation, and improve the innovation of local governments in formulating environmental policies and the enthusiasm of implementing environmental policies.
2. Give full play to the conduction effect of green technology innovation in environmental regulation and coastal marine ecological environment. On the one hand, the government should actively promote the establishment of a green technology innovation system with enterprises as the main body. While the government puts forward clear requirements on emission standards and production technology, it should effectively utilize market means, such as environmental protection tax, environmental subsidies, and emission trading, to stimulate the enthusiasm of enterprises to carry out green technology innovation. On the other hand, the government should gradually improve the transformation mechanism of scientific and technological achievements, accelerate the ownership reform of scientific and technological achievements, promote the market-oriented application of green innovation achievements, build a green technology cooperation and exchange platform, and consolidate the foundation for the diffusion and application of green technology.
3. Pay attention to the trans regional transfer and treatment of coastal marine pollution and promote regional joint prevention and control. Coastal city governments should break through the shackles of "mutual prevarication and respective formation," pay attention to the coordination and cooperation with adjacent regions in marine environmental governance, and strengthen joint environmental law enforcement and supervision. Under the overall coordination of the central government, building a platform for environmental protection information exchange and sharing, establishing a coordination mechanism for marine pollution prevention and control, and preparing a

unified plan for regional ecological environment governance are vital.

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 author.

AUTHOR CONTRIBUTIONS

QH put forward the idea and revised the paper; JM analyzed the data and wrote the paper; XW contributed to the conceptual framework of the methodology. All authors have read and approved the final manuscript.

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