Exploring the affecting mechanism between environmental regulation and economic efficiency: new evidence from China's coastal areas

by Zheng, H., Zhang, J., Zhao, X. and Mu, H.

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Harper Adams University

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Keywords: sustainable development, environmental regulation; economic efficiency; Porter Hypothesis (PH); SE-SBM model

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Hui Zheng[a,c,*], Jingchen Zhang[a], Xin Zhao[a,c], Hairong Mu[b, *]

a. School of Economics, Ocean University of China, Qingdao, Shandong, 266100, China;

b. Department of Land, Farm and Agribusiness Management, Harper Adams University, Newport, Shropshire, TF10 8NB, UK;

c. Institute of Marine Development, Ocean University of China, Qingdao, Shandong, 266100, China.

Abstract

China's commitment to building the country into a maritime power has seen a rapid growth in its marine economy in recent years. In the meantime, increasing concern over environmental degradation and sustainability has made the government to shift attention from marine development to marine ecosystem protection by formulating more environmental policies. There has been a long-standing debate between traditional views and well-known Porter Hypothesis (PH) over the impact of environmental regulation on the competitiveness and efficiencies of firms and industries. Aiming to obtain empirical evidence of the possible impact, this paper uses the Super-Efficiency Slacks-Based Measure (SE-SBM) model to calculate economic efficiency considering undesired outputs and the system Generalized Moment Method (GMM) to examine the relationship between the two variables, using data from 11 provinces and cities in China's coastal areas. The results seem to support the presence of the PH in Chinese marine economy and show a U-shaped relationship between environmental regulation and economic efficiency. In addition, it is also found optimization of industrial structure can impose a positive effect on economic efficiency, while capital investment and science and technological innovations may have a negative effect. Based on these results, the paper puts forward some recommendations for policy makers.

[*] Corresponding author

Hui Zheng is an associate professor at the School of Economics, Ocean University of China. Email: qdzhouc@163.com;

Jingchen Zhang is a postgraduate at the School of Economics, Ocean University of China. Email: claire58@foxmail.com;

Xin Zhao is a professor at the School of Economics, Ocean University of China. Email: zx@ouc.edu.cn;

Hairong Mu is a senior lecturer at Harper Adams University. Email: hmu@harper-adams.ac.uk.

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1. Introduction

The marine economy is made up of both industry and geography. It is the sum of economic activities that take place or use the marine environment, or produce goods and services necessary for those activities, and make a direct contribution to the national economy (SCPRC, 2003)[1]. With the gradual depletion of terrestrial resources and the rapid development of marine science and technology, the marine sector has become a new engine and highly contributed to the world economic development. The total output value of global marine industry reached CNY10 trillion (approximately US$1.52 trillion) in 2017, accounting for 10% of the world's GDP (CMEIN, 2017). However, along with the success of the marine economy that is heavily dependent on resources, increasing concerns over challenges such as over-exploitation of marine resources and degradation of marine ecosystem have been brought up to governments' attention in many countries in recent years. A number of coastal countries like Canada and the US (Zhao *et al.*, 2018b) as well as the EU have launched programs that explicitly aim at strategic initiatives to improve management of marine resources and promote sustainable development of coastal zones (Karnauskaitė *et al.*, 2018).

As one of the world's biggest marine economies, China has attached great importance to its marine development over the last decade. Since 2012 the marine economy has seen an average growth of 7.2% annually, reaching USD1.12 trillion in 2017 (Xinhuanet, 2018). Like other countries, China also faces challenges such as environmental protection and sustainable development in the marine economy. To meet those challenges, in its 13th Five-Year Plan launched in March 2016, the central government maps a strategic vision for the country's socioeconomic and resource development covering the period 2016-2020. This is the first time ever since the Chinese economic reform in 1978, environmental protection is placed as one of the priorities on par with economic development. In the meantime, the Five-Year Plan also incorporates marine ecosystem protection as a significant component of the central government's environmental agenda (Cao *et al.*, 2016).

Since then a series of environmental protection policies have been promulgated at both national and provincial levels. For instance, in March 2017, the State Council issued the 'Regulations on Prevention and Control of Vessel Pollution to the Marine Environment (Revised Edition)', the 'Regulations on Prevention and Control of Marine Environmental Pollution from Marine Engineering Construction Projects', the 'Regulations on Dumping of Wastes to the Sea (Revised Edition)' and so on. The main coastal provinces such as Jiangsu, Guangdong, Zhejiang and Shandong (see Fig.1) have all enacted and enforced preventative

[1]The marine economy includes industries such as the fisheries, marine transportation as well as the offshore oil and gas industry.

environmental regulations and legislations that aim to strengthen control in the use of marine resources as well as reduce emissions and thereby improve the quality of marine environment.

However, these emission reduction-oriented environmental policies inevitably put China into a dilemma, i.e. fulfilling a dual mission of promoting industrial growth and at the same time protecting environment. In this respect, regulations can be a double-edged sword. On the one hand, it may increase growth when it improves economic efficiency by reducing market failures. However, on the other hand, it may also create unnecessary burden on the affected firms whose output and productivity are likely to reduce. Hence, the publication of those environmental policies gives rise to the controversial question concerning the effects of environmental regulation on economic efficiency, which has attracted growing interests from both the government and the academia.

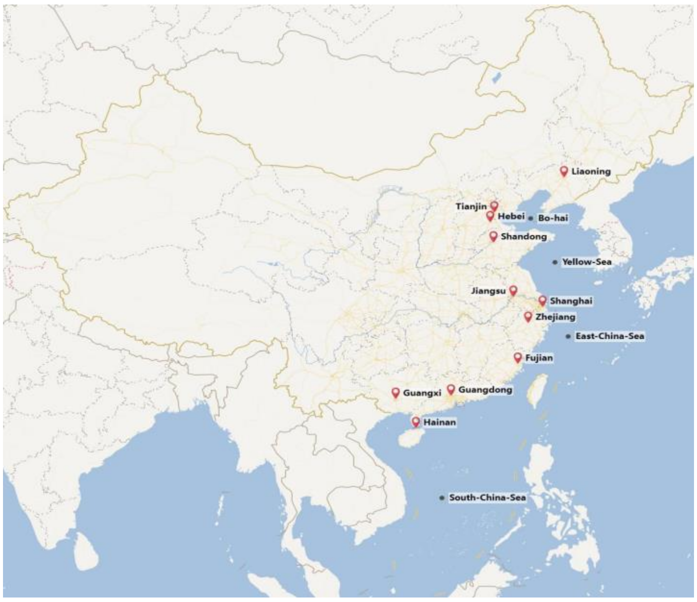


Figure1 Map of China and studied coastal areas

This paper seeks empirical evidence to provide an answer to the above question by looking into China's marine industry, using data from 11 coastal provinces and cities. The reminder of the paper is organized as follows. Section 2 reviews the related literature. Section 3 introduces the empirical models and data source, followed by the results presented in Section 4. The final section concludes the paper with further discussion and puts forward some policy suggestions.

2. Literature review

The question of how environmental regulation affect economic efficiency has long been widely debated. When the National Environmental Policy Act (NEPA) was signed in the United States to begin the 1970s as the environmental decade (Jaffe *et al*., 1995), there have been considerable concerns about the potential impacts of various environmental regulations on economic performance of industries and businesses.

The traditional view held by neoclassical economists argues that (strict) environmental policies are damaging to businesses by imposing unnecessary administrative and compliance costs on the targeted industries, which can adversely affect productivity and competitiveness with possible adverse implications for economic growth and jobs. However, Porter (1991) and Porter and van der Linde (1995) challenged the conventional wisdom with an alternative view, known as 'Porter Hypothesis' (PH). They commented that studies should not just focus on static cost impacts and further argued that well-designed environmental regulations can actually trigger innovation that may partially or more than fully offset compliance costs and enhance firms' productivity.

Over the past 20 years since the PH originated, a vast literature has proposed many theoretical justifications and alternative theories that might explain the PH (Ambec *et al*., 2013). Along with these theoretical developments, there has been a substantial body of empirical research investigating the validity of the PH in practice but the results are ambiguous (Koźluk and Zipperer, 2013). Most studies in early days focused on the US and attributed the slowdown in productivity growth observed in the US to environmental regulations (Christiansen and Haveman, 1981; Gollop and Roberts, 1983; Dufour *et al.*, 1998; Boyd and McClelland, 1999). But Berman and Bui (2001) studied a period of sharply increased regulation between 1979 and 1992 looking into some of the most heavily regulated manufacturing plants (the oil refineries) in the US. They concluded that measures of the cost of environmental regulation may be significantly overstated as abatement can increase productivity. A number of other studies have reported that productivity is either unaffected or enhanced by environmental regulation (Dechezleprêtre and Sato, 2014). It seems that more recent studies tend to support in favor of the PH in many other countries. Ramanathan *et al.* (2010) studied the industrial sectors in the UK and indicated that environmental regulations are significant in improving economic performance of those sectors. Chalermthanakon and Ueta (2011) used data from the automobile, food and electronics industries in Japan from the 2003-2009 period with the results being likely to support the PH. Yang *et al.* (2012) examined the influence of environmental regulation on R&D and productivity in Taiwan using an industry-level panel dataset for the 1997-2003 period. Their empirical results show a significant positive correlation between environmental regulation and productivity. Rubashkina *et al.* (2015) focused on the manufacturing sectors of European countries between 1997-2009 and found evidence of a positive impact of environmental regulation on the output of innovation activity. A very recent study undertaken by Manello (2017) analyzed a sample of chemical firms from Italy and Germany to test the HP and supported the presence of win-win opportunities. All these empirical evidence on the impact of environmental regulations on productivity and innovation has been rather country- and context-specific and thus inconclusive. Recently some researchers (Albrizio, 2017) have attempted to identify a dynamic relationship between environmental policies and productivity growth from a global perspective combining industry and firm level results, which suggests a tightening of environmental policy is associated with a short-term increase in industry level productivity growth in the most technologically-advanced countries.

The controversial issue about environmental regulation and economic performance has also been gaining rapidly importance and receiving great academic interest in China. Empirical studies on the subject have mushroomed in recent years aiming to offer data support for policy recommendations. Evidence has been collected from various industries, such as manufacturing industry (Jiang *et al.*, 2018; Wang *et al.*, 2018; Yuan and Xiang, 2018), steel industry (Zhu *et al.*, 2018), construction industry (Zhang *et al.*, 2018b) and so on. Like previous studies elsewhere, the results in the context of China are mixed as well. Some scholars find the empirical support for the PH using either provincial or industrial panel data (Pan *et al.*, 2017; Wang and Shen, 2016). The results from other studies, however, indicate that the PH is not tenable (Li *et al.*, 2018; Jin *et al.*, 2019). The mixed results of the effect of environmental regulation on productivity can be explained by different political attribute of the sample cities (Zhang *et al.*, 2017). In addition, research indicates the links between the two variables are not linear (Li and Ramanathan, 2018). A handful of studies attempting to identify the optimal intensity of the environmental regulation find either a 'N-shaped' or an inverted 'U-shaped' relationship between regulation intensity and the total factor productivity (TEP) in other industries (Shen *et al.*, 2019; Zhao *et al.*, 2018a).

Despite the above vast empirical literature, very little evidence has been documented in the context of the marine economy. When looking into the influencing factors for productivity of marine industries, both Ding *et al.* (2015) and Gai *et al.* (2016) concluded that environmental regulation has an insignificant positive influence on economic efficiency. Ren *et al.* (2018) calculated economic efficiency with undesired outputs using the Global Malmquist-Luenberger (GML) index model, and attributed the improved efficiency within China's marine economy to technological progress.

The above review of related literature has identified a gap in the existing research, i.e. the PH needs to be further tested in the context of China's marine economy. To investigate the dynamic relationship between environmental regulation and economic efficiency (either linear or non-linear), in the following section, we first calculate economic efficiency considering undesired outputs and then adopt a panel data model to identify the threshold.

3. Method and Data

3.1 SE-SBM model

The Data Envelopment Analysis (DEA) model was originally developed by Charnes *et al.* (1978) to evaluate productive efficiency with decision making units (DMUs). Then, the slacks-based measure (SBM) model and the super-efficiency slacks-based measure (SE-SBM) model were proposed to solve the radial and angular dimensions bias of the traditional DEA model (Tone, 2001; Tone, 2002). The input-output index is a key component of the model. In general, the input indices include labor, land and capital, which can be represented by the quantity of sea-related employment, the scale of marine pillar industries[2] and the fixed asset investment in marine economy, respectively (Di *et al.*, 2009; Joseph and James, 2012; Wanke, 2013; Zou *et al.*, 2017; Zheng *et al.*, 2017). The gross ocean product (GOP) has been widely used to reflect desired outputs in marine economy (Ding *et al.*, 2015; Gai *et al.*, 2018). Recently, undesired outputs, such as waste water and waste gas as well as solid waste, have also been taken into consideration to assess the effect of the

[2]Marine pillar industries contain marine fishery, offshore oil and gas industry, marine salt industry, marine chemical industry, marine biopharmaceutics industry, marine power industry, seawater utilization industry, marine shipbuilding industry, ocean engineering construction industry, maritime transportation and coastal tourism industry (SBCME, 2018).

by-products on the environment when evaluating economic efficiency (Song *et al.*, 2013; Zhao *et al.*, 2018a; Han *et al.*, 2018).

In the following, the SE-SBM model is used to calculate economic efficiency. In order to reduce the systematic bias, economic efficiency is estimated on the basis of CRS (constant returns to scale) model (Asmild *et al.*, 2004). Suppose there are *n* DMUs in the production system and each DMU has three vectors: input (x), desired outputs (y^g) and undesired outputs (y^b). Each DMU produces p desired outputs ($y^g = \left(y_1^g, \cdots, y_p^g\right) \in R_+^p$) and q undesired outputs ($y^b = (y_1^b, \cdots, y_q^b) \in R_+^q$) with m inputs ($x = (x_1, \cdots, x_m) \in R_+^m$). The SE-SBM model is thus given by the following:

$$\delta *= min \frac{1 - \frac{1}{m}\sum_{i=1}^{m}\frac{s_i^-}{x_i}}{1 + \frac{1}{p+q}(\sum_{r=1}^{p}\frac{s_r^+}{y^g{}_{rk}} + \sum_{r=1}^{q}\frac{s_r^{b-}}{y^b{}_{rk}})}$$

s.t.

(1

$$\lambda X + s^- = X_k$$
$$\lambda Y^g - s^+ = y_k^g$$
$$\lambda Y^b + s^{b-} = y_k^b$$
$$s^{b-}, s^+, \lambda \geq 0$$

where s^-, $s^+$and$s^{b-}$are slack variables of input vectors, desired output vectors and undesired output vectors, respectively. λ is a weight vector. Input-output indices can then be derived and presented in Table 1[3]. Following Ren *et al.* (2018) and Wang *et al.* (2013), the improved entropy method is adopted to integrate the marine waste water, marine waste gas and marine solid waste ("three wastes") as the index of environmental pollution.

Table 1 Input-output indices

Statistical variables / Indicators	Inputs					Outputs	
	Labor	Land			Capital	Desired outputs	Undesired outputs
	Sea-related personnel (10000 Person)	Mobile fishing boats at the end of year	Major coastal ports	Travel agencies	The total fixed asset investment (Billion CNY)	The annual gross ocean product (Billion CNY)	Marine pollution emission index
Mean	269.99	41064.76	216.48	869.42	9630.62	2594.42	13903.00
Max	852	131608	2200	2099	48312.44	13229.8	212157
Min	58	759	27	143	193.45	57.66	51521
Median	196	38574.5	122.5	772	5853	1715.895	51521
Standard deviation	193.06	32365.18	257.19	537.69	9949.95	2603.83	30293

[3] We use the number of mobile fishing boats at the end of year, the number of major coastal ports, and the number of travel agencies to measure inputs of marine fishery industry, marine port transportation industry and coastal tourism industry, respectively.

3.2 The threshold regression model

Next, the threshold regression model is adopted to analyze the relationship between environmental regulation and economic efficiency. In the model, economic efficiency (EE) calculated is set as the response variable and the intensity of environmental regulation (ER) as the explanatory variable. Suppose there is a single threshold (γ), and thus the static threshold regression model is given as follows:

$$EE_{kt}=\alpha+\alpha_1 ER_{kt}*1(M_{kt} \leq \gamma) + \alpha_2 ER_{kt}*1(M_{kt} > \gamma)+\beta_i X_i+\mu_{kt} \quad (1)$$

M_{kt} is the threshold variable for province *k* in year *t,* which is determined by the fixed-point method. α_1 and α_2 are the coefficients of the threshold variables. 1(•) is an indicative function, which equals 1 if the expression in the parentheses is true and 0 if otherwise. μ_{kt} is a random interference. X_i is a control variable that may affect economic efficiency. β_i is the coefficient of X_i (*i* = 1, 2, ⋯).

Further, to estimate the dynamic relationship between the two variables, the system GMM (Generalized Method of Moments) method is used to examine whether there exists a time lag. The dynamic threshold regression model is given by the following:

$$EE_{kt} = \alpha + \alpha_1 EE_{k(t-1)} + \alpha_2 {ER^2}_{k(t-1)} + \alpha_3 ER_{k(t-1)} + \alpha_4 ER_{kt} + \alpha_5 ER_{kt}^2 + \beta_i X_i + \mu_{kt} \quad (2)$$

Environmental regulation refers to the behavioral norms of the state that restrict environmental pollution behavior and improve environmental quality according to the legal system. Individual indicators such as pollution abatement cost and pollution control investment and comprehensive indicator of various pollutant emissions are common method for the measurement of the intensity of environmental regulation (Berman and Bui, 2001; Pan *et al.*,2017; Manello *et al.*, 2017; Wang and Shen, 2016; Zhang *et al.*, 2018a). Considering the data availability, in the above model the intensity of environmental regulation (*ER*) is measured by the regional environmental pollution control investment (Cole and Elliott, 2003; Wu, 2006; Shen, 2012). In marine economy, capital, technology and industrial structure adjustment are all essential for efficiencies (Zhao *et al.*, 2016; Song *et al.*, 2017). The indicators (X_i) of these are captured by the following:

(1) Total capital investment (CI): Capital investment can influence economic efficiency differently in various areas. We use the ratio of the total fixed asset investment (FAI) to the gross ocean product (GOP) to reflect the total capital investment in the chosen areas:

$$CI = FAI/GOP$$

(2) The level of science and technological innovation (STI): The development of marine economy is largely driven by innovation of marine science and technology. We use the number of marine science and technology projects to reflect the level of science and technological innovation.

(3) The optimization of marine industrial structure (IS): Marine tertiary industry plays an important role in marine economy and contributes to the growth. We use the ratio of gross ocean product of the tertiary industry (GOP_3) to the gross ocean product of the whole industry (GOP) as the indicator for marine industrial structure optimization:

$$IS = GOP_3 / GOP$$

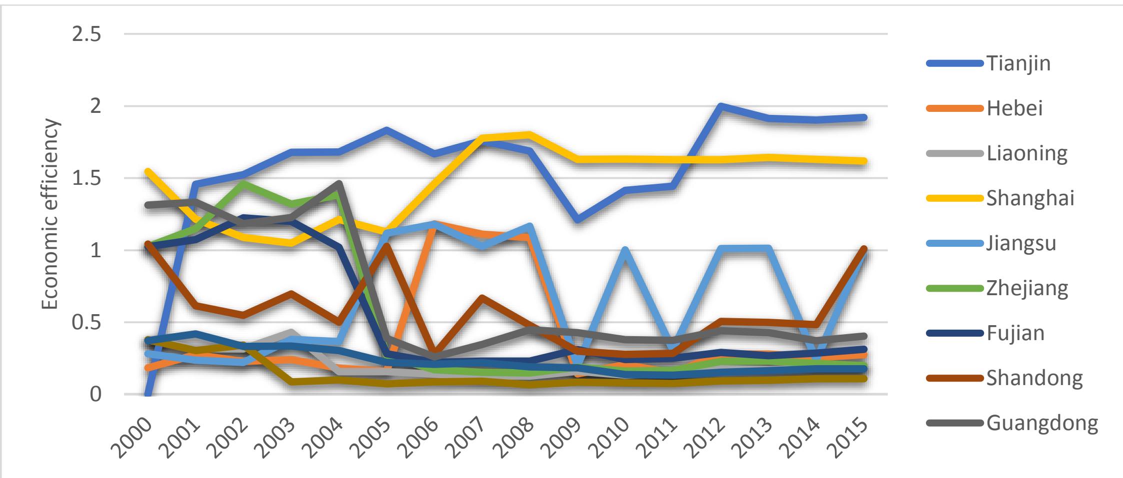
3.3 Data sources

All the data are from the China Statistical Yearbook (2000-2015), the China Marine Statistical Yearbook (2000-2015), the China Fishery Statistical Yearbook (2000-2015) and the China Energy Statistics Yearbook (2000-2015). All the yearbooks are published annually and edited by National Bureau of Statistics of China (NBS), which is responsible for collection and the research of the nation's overall statistics. Admittedly, in recent years, Chinese official statistics have been increasingly criticized for lack of transparency and problems of data inconsistency, which casts doubt on reliability of data used in research. However, there hasn't been any evidence to show that official data has been deliberately manipulated and falsified (Plekhanov, 2017). Instead, it has been acknowledged that the NBS appears to be making sincere efforts to prevent data falsification (Holz, 2003). Even alternative estimates of Chinese economic indicators cannot be immune to criticism either. As official publication of statistics is currently the only source from where comprehensive data can be obtained for academic research, many studies tend to extract data from the China Yearbooks, which at least provide some basis for comparison[4].

4. Results

4.1 Results of economic efficiencies

Figure 2 shows the results of economic efficiencies with undesired outputs for the 11 coastal provinces and cities[5]. Overall, the economic efficiencies in the study areas seem relatively low (mostly less than 1 and close to 0), but tend to be on the rise with fluctuations. In particular, economic efficiencies were slightly up during the 10th Five-Year Plan period (2000-2005), followed by a phase of adjustment (2006-2009), and then started to climb again during the 12th Five-Year Plan period (2011-2015).



[4] An interesting topic for future research would be to apply the same methods proposed in the analysis of more developed economies statistics to provide some basis for comparision.

[5] The specific efficiency value for each area can be found in Appendix A (Table A.1).

Figure 2 Economic efficiencies of coastal areas in China between 2000 and 2015

4.2 The dynamic effect of environmental regulation on economic efficiency

In this section, the system GMM method is adopted to analyze the effect of environmental regulation with the time lag. The annual dummy variables and regional dummy variables are set to test the time-lag effect and the individual effect, respectively. Table 2 shows the first-order lag item of environmental regulation which has a significant effect on economic efficiency at the confidence interval of 95%[6]. Only AR(1) is significant in the sequence correlation , and the horizontal residual auto-correlation does not exist.

Table 2 The results of the dynamic threshold regression model

variables	co-efficient	variables	co-efficient
EE_{t-1}	-1.0637*	ER_{t-1}	-14.7644**
ER_t^2	13.8213**	IS	36.6391**
ER_t	-11.1221**	CI	-0.00329
ER_{t-1}^2	13.1023**	STI	-0.00199**
α	-10.1786*		

The significantly positive coefficient of the squared term of ER (ER_t^2) verifies a U-shaped relationship between environmental regulation and economic efficiency. The negative coefficient of ER_{t-1} and positive coefficient of ER_{t-1}^2 indicate that environmental regulation can initially negatively affect economic efficiency and then turn to be positive after a certain point.

In the meantime, there exists a time lag for regulation to take effect. This result is partially consistent with those of Song *et al.* (2017), Cai and Zhou (2017) and Zhang *et al.* (2018b), which have all confirmed the existence of the PH in China's land economy. However, their findings show an inverted U-shaped relationship between the two variables and thus imply excessive environmental regulations can impose a negative impact on economic efficiency when they reach a certain level. A striking contrast found in our study is that a U-shaped relationship instead exists in China's marine economy, at least in the areas chosen for the study, which suggests the tightening environmental regulation should be effective in improving efficiencies after exceeding a certain level.

4.3 Threshold effect analysis

In the previous section, we have verified a U-shaped relationship between environmental regulation and economic efficiency. In this section, we further estimate the threshold from where a radical change occurs in the effect of regulations. The self-sampling test of threshold effect and the regression results are

[6]The result of the Sargan test strongly supports the original hypothesis, i.e. the system GMM is feasible in measuring this dynamic relationship between environmental regulation and economic efficiency.

given in Table 3. The significant P-value indicates the existence of a single threshold rather than a double threshold with the threshold value being 0.911 (γ=0.911), which further confirms the U-shaped rather than a N-shaped relationship found in other industries by Shen *et al.* (2019). This relationship can be clearly seen in Figure 3.

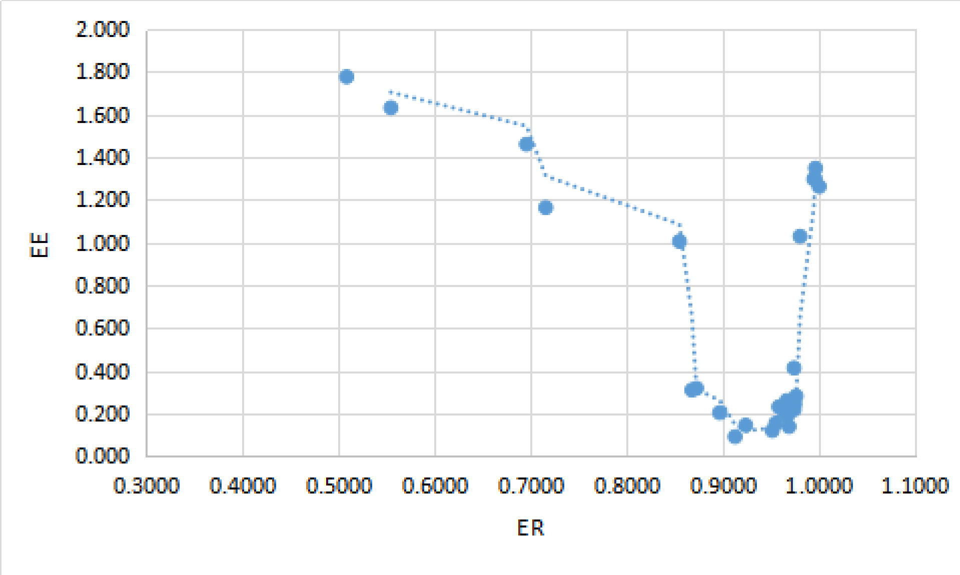


Figure 3 U-shaped relationship between environmental regulation and economic efficiency

Intuitively, the relationship between environmental regulation and economic efficiency can be interpreted as follows. Before the certain level (γ) is reached, strengthening of environmental regulation will cause economic efficiency to decline. This is because the costs associated with environmental regulation (such as administrative and compliance costs) exceeds its benefits (such as increased efficiency) brought to the industry in the early stage. When the certain level (γ) is surpassed, the benefits of environmental regulation turn to outweigh the associated costs, which as a result boosts economic efficiency. This result is in line with some of the literature focusing on the land economy where environmental regulation increases the cost of enterprises but in the meantime offsets the adverse effects, which in turn generates revenues by stimulating innovation (Porter, 1991; Cole, 2008; Baiti *et al.*, 2017).

Table 3 The self-sampling test of threshold effect and regression results

The self-sampling test of threshold effect						
Number of thresholds	F-statistics (P-value)	BS number	Critical value			The threshold values [95% -Confidence interval]
			1%	5%	10%	
Single threshold	24.778*** (0)	3	3.53	3.53	3.53	0.911 [0.900, 0.919]
Double threshold	5.913 (0.401)	3	7.281	7.281	7.281	0.718 [0.081, 0.895]
						0.897 [0.891,0.907]

Threshold regression result					
Explanatory variables	Co-efficient	P-value	Control variables	Co-efficiency	P-value
ER ($M_{kt} \leq \gamma$)	-0.3171	0	IS	-1.9331	0.006
			CI	-0.0398	0
			STI	-0.0002	0.031
			α	1.7000	0
ER ($M_{kt} > \gamma$)	0.3601	0	IS	-0.8871	0.019
			CI	-0.0501	0
			STI	-0.0003	0.009
			α	1.4127	0

The aforementioned result can be further supported by Table 4 in which the 11 coastal provinces and cities are grouped according to their threshold values. It can be noted that in 2000 all the provinces and cities have the values below the threshold, which implies environmental regulation and economic efficiency are negatively related for all the study areas in that year. However, in 2015, three areas (Tianjin, Hebei and Jiangsu) surpassed the threshold value, which implies environmental regulation was supposed to start imposing positive effect on economic efficiency in these areas. It can be reinforced by the results in Figure 2 where there is a noticeable increase in economic efficiencies from 2014 to 2015 for Tianjin, Hebei and Jiangsu where environmental regulation became more tightening during that period (PEOPLENET, 2015; SINANET, 2015; GOV, 2015).

Table 4 Threshold values of 11 coastal provinces and cities in China

Threshold \ Year	2000	2015
ER≤0.911	Tianjin, Hebei, Shanghai, Liaoning, Shandong, Fujian, Jiangsu, Zhejiang, Guangdong, Guangxi, Hainan	Shanghai, Liaoning, Shandong, Fujian, Zhejiang, Guangdong, Guangxi, Hainan
ER>0.911		Tianjin, Hebei, Jiangsu

4.3 Further analysis

It can be also noted from Table 2 that the co-efficient of industrial structure (IS) is significantly positive which implies upgrading industrial structure can contribute to improving efficiencies. As such, the government's efforts to transform and upgrade traditional marine industries are conducive to marine economy being 'less pollution, higher efficiency' (Ozturk and Acaravci, 2013). Moreover, the effect of capital investment (CI) on economic efficiency tends to be negative although not significant. Generally, investment plays an important role in driving economic growth through increased production of goods and services. Nevertheless, the increased productivity level may inevitably lead to increased pollution and as a result cause environmental degradation (Jensen, 1996; Tamazian and Rao, 2010; Jalil and Feridun, 2011; Shahbaz., 2013), which in turn slows down the development of the whole economy (Cai and Zhou, 2017). In addition, it is found (somewhat surprisingly) that science and technological innovation (STI) has a negative impact on economic efficiency. This may be due to the relatively low conversion rate and long cycle of science and technological innovations, which has been already mentioned in the existing literature (Zhao *et al*., 2016; Zhai, 2018; Yan *et al*., 2018). To solve this problem, China's National Science and Technology Development Plan (NSTDP) has proposed to establish a conversion system to improve the conversion rate of science and technological innovations and aimed to enhance the rate to be over 55% by 2020 (SOA, 2016).

5. Conclusions and Policy Implications

As a large country with a long coastline, China has experienced rapid development in its marine economy, which, in the meantime, has posed continuous pressure on the ecological environment. The central government has committed to strengthening control, which includes new legislation and regulation to combat the increasing environmental problems. But how the stringent regulation will affect economic efficiency still remains unclear.

Over the past 20 years since the formulation of the Porter Hypothesis (PH), a vast literature has proposed many theoretical justifications and alternative theories that might explain the relationship between environmental regulation and economic efficiency. Along with these theoretical developments, there has been a substantial body of empirical research investigating the validity of the PH in practice but the results are ambiguous. To further test the PH in marine economy, this paper is intended to assess dynamic effects of environmental regulation on economic efficiency, using data from the 11 coastal provinces and cities in China.

We find that there exists a non-linear relationship between environmental regulation and economic efficiency with one single threshold. Environmental regulation will unavoidably impose administrative and compliance costs on the targeted industries, which can adversely affect efficiency. This occurs under the condition when the intensity of regulation is lower than the threshold and as a result economic efficiency tends to be declining with more stringent regulations, which implies the costs incurred outweigh the increased benefits brought by regulations. But the effect turns to be exactly opposite when the intensity of environmental regulation exceeds the threshold, after which the improved ecological environment and innovation adoption can partially or more than fully offset compliance costs and enhance efficiency and therefore economic efficiency turns to be rising with more stringent regulations. This result proves the validation of the PH, at least in the 11 study areas in China. Nonetheless, it must be pointed out that the conclusion of a U-shaped relationship between the two is drawn from the data over the period 2000-2015. One cannot generalize the result by assuming that economic efficiency to be infinitely improved by excessive regulations, which obviously does not make any sense. We thus speculate there may exist another turning point where the effect of environmental regulation on efficiency will alter again, which is worth further investigation in the future.

In addition, we also find optimization of industrial structure can impose a positive effect on economic efficiency, while capital investment may have a negative effect. Although the results show the effect of science and technological innovations is negative, it cannot be underestimated the importance of innovations, but may be attributed to the low conversion rate and long cycle of projects. Furthermore, it is confirmed the existence of a delay between government action and its effects, i.e. strengthening environmental regulation normally takes a certain period of time to have an effect on efficiency.

Based on the above findings, several recommendations can be made for policy consideration. More emphasis should be placed on continuity and consistency of environmental policy and regulations. For areas with relatively loose regulations and thus poor marine ecological environment, such as Liaoning province, it is advised to gradually introduce more strict environmental governance, which, for instance, can issue a county-level directory for marine industries to provide guidance for practice as well as accelerate optimization of industrial structure. For areas with intensive regulations and well-conserved ecological environment, such as Jiangsu province, more focus should be given to future regulations to ensure sustaining improvement of economic efficiency in the marine economy.

An issue standing in the way of the effectiveness of policies is the time lag that occurs from the implementation of a policy to the actual evidence of its impact. Realizing the delay in the effect, it should be avoided to make frequent changes in regulations, although it may be necessary to establish a policy evaluation mechanism to ensure the correct direction of the policy. In addition, the government and targeted industries can take risk transfer and preventative measures in order to minimize the short-term adverse effect of environmental regulations.

Since technological innovation can be a driver for new production alternatives with higher efficiencies and plays a significant role in environmental protection and conservation, investment in science, technology and innovation is essential for sustainable development of the marine economy. We advise to construct such a technological innovation mechanism that provides a platform where cooperation and collaboration can be achieved between educational institutions, marine science talents and leading firms. This can effectively help speed up the realization of innovations in practice. Besides, intermediary organizations also have a role to play and are conducive to coordinating the supply and demand of cutting-edge technologies, which provides support to enhance conversion rate of science and technological innovations.

Author Contributions

Hui Zheng and Jingchen Zhang conceptualized the study, synthesized the data analysis plan, analyzed the data, interpreted the findings and led the writing of the manuscript. XinZhao and Hairong Mu contributed to the analysis and write-up of the manuscript. All authors read and approved the final version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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Appendix A

Table A.1 Economic efficiencies of 11 coastal provinces and cities in China

	Tianjin	Hebei	Liaoning	Shanghai	Jiangsu	Zhejiang	Fujian	Shandong	Guangdong	Guangxi	Hainan
2000	1.512	0.184	0.377	1.546	0.282	1.024	1.024	1.043	1.312	0.378	0.372
2001	1.457	0.275	0.317	1.216	0.236	1.148	1.074	0.614	1.333	0.304	0.418
2002	1.523	0.229	0.314	1.089	0.222	1.459	1.224	0.547	1.184	0.342	0.332
2003	1.679	0.241	0.43	1.049	0.38	1.319	1.199	0.695	1.227	0.087	0.335
2004	1.681	0.181	0.157	1.214	0.366	1.383	1.019	0.501	1.462	0.099	0.303
2005	1.832	0.159	0.157	1.127	1.117	0.267	0.281	1.027	0.388	0.073	0.221
2006	1.667	1.183	0.14	1.461	1.179	0.171	0.221	0.277	0.258	0.086	0.208
2007	1.758	1.112	0.129	1.777	1.027	0.153	0.231	0.667	0.346	0.091	0.219
2008	1.688	1.087	0.127	1.801	1.166	0.148	0.231	0.478	0.448	0.066	0.19
2009	1.21	0.142	0.159	1.631	0.197	0.187	0.31	0.298	0.428	0.083	0.184
2010	1.416	0.206	0.133	1.632	1.002	0.161	0.242	0.276	0.378	0.079	0.137
2011	1.443	0.148	0.148	1.628	0.308	0.166	0.25	0.284	0.375	0.075	0.132
2012	1.999	0.279	0.177	1.627	1.012	0.227	0.289	0.506	0.442	0.092	0.152
2013	1.914	0.28	0.17	1.644	1.014	0.23	0.269	0.499	0.427	0.096	0.163
2014	1.904	0.254	0.179	1.63	0.239	0.214	0.286	0.482	0.373	0.108	0.176
2015	1.92	0.274	0.202	1.62	1.001	0.2	0.313	1.01	0.403	0.109	0.177

This manuscript has not been published and is not under consideration for publication elsewhere. We have no conflicts of interest to disclose.

All authors have read and approved the final version of the manuscript.

Thank you for your consideration, and we look forward to hearing from you at your earliest convenience.

Sincerely, Hui Zheng, Jingchen Zhang, Xin Zhao, Hairong Mu