Applied Energy Symposium 2021: Low carbon cities and urban energy systems
September 4-8, 2021, Matsue, Japan
Paper ID: 17

Environmental regulation and influence on energy-environmental performance: Evidence on the Porter Hypothesis from China's iron and steel industry

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ABSTRACT

Environmental regulation is a critical instrument for achieving sustainable economic and social development. The iron and steel industry is highly polluting and energy-consuming, posing a significant threat to China's environmental sustainability. Based on the panel of Chinese provincial-level data from 2000 to 2017, this paper empirically examines how environmental regulation affects the iron and steel industry's green development. The findings show that there is a U-shaped relationship between environmental regulation and energy-environmental performance. Low environmental regulation intensity inhibits the improvement of energy-environmental performance. But as the regulation intensity increases, it contributes to the advancement of energy-environmental performance. Environmental regulation affects the industrial energy-environment performance through technological innovation, and the relationship between environmental regulation and technological innovation presents a U-shaped relationship. There are noticeable regional differences in the impact of environmental regulation on energy-environmental performance. The findings provide new evidence to confirm the Porter Hypothesis. Finally, this paper provides policy suggestions for further energy-environmental performance improvements in China's iron and steel industry.

Keywords: Environmental regulation, Energy-environmental performance, Porter Hypothesis, Tobit model

NONMENCLATURE

Abbreviations	
ISI	Iron and steel industry

1. INTRODUCTION

Environmental regulation is considered an effective means of mitigating severe environmental pollution problems (Sun et al., 2019). While environmental regulation can eliminate the negative environmental impacts of economic activities, it increases production costs, inhibits industry development, and slows down macroeconomic growth (Blackman et al., 2010). Many are concerned that stringent environmental regulations will undermine the competitiveness of China's iron and steel industry (ISI). In the dynamic analysis framework, the Porter Hypothesis holds that the increase in the cost of production factors caused by strict regulations could stimulate process innovation and product innovation (Porter and Linde, 1995). It can be compensated by corresponding innovation to offset the increased costs caused by regulations, thus improving industry competitiveness. Governments and companies would prefer the Porter Hypothesis to apply to environmental regulation in the ISI. That is, environmental regulation can enhance the competitiveness of ISI while solving ecological pollution.

The goal of carbon neutrality by 2060 puts environmental protection in a more critical position. The environmental constraints faced by the ISI will change from the "relative constraint" on carbon emission intensity to the "absolute constraint" on total carbon emission. The ISI faces more stringent environmental requirements and supervision. In this context, we aim to evaluate the competitiveness of China's ISI under environmental regulation. Based on the data from 2000 to 2017, this paper constructs the energy-environmental performance index of ISI and distinguishes different environmental regulations (command-based, market-based, and public-based regulations). The study further discusses the interaction, influence mechanism, and the regional heterogeneity between environmental regulations and the energy-environmental performance of ISI.

The innovation of the study mainly includes three aspects: (1) We explore the impact of environmental regulation on energy-environmental performance in the sample of China's ISI. It will contribute to verify the Porter Hypothesis in the context of China. (2) By further classifying three environmental regulation types, we provide an in-depth analysis of the influence mechanism between environmental regulation and energy-environmental performance. Moreover, this paper uses different indicators to measure the energy-environment performance and technological innovation, which can further ensure the study's reliability. (3) We further investigate the regional heterogeneity of environmental regulations on energy-environmental performance by using the latest provincial panel data. Our study is beneficial to promoting the industrial transformation in different regions to a green growth path.

2. LITERATURE REVIEW

2.1 Relationship between environmental regulation and competitiveness

The relationship between environmental regulation and industry competitiveness has always been one of the focuses of academic attention. The current studies on the effect of environmental regulation mainly focuses on the Compliance Cost Hypothesis (Barbera and McConnell, 1990) and the Porter Hypothesis (Porter and Linde, 1995).

The Compliance Cost Hypothesis argues that environmental regulation increases firms' expenditure on environmental protection, resulting in higher production costs. These additional costs inevitably influence the industry's investment decisions, productivity, and profitability (Gray and Shadbegian, 2003).

Contrary to the Compliance Cost Hypothesis, Porter and Linde (1995) believed that firms' production cost pressure under environmental regulation would force them to innovate and promote industrial structure upgrading. In this way, environmental regulation can improve production efficiency and enhance firms' competitiveness (Jaffe et al., 2002). Many researchers are working on the Porter hypothesis in greater depth. These studies showed that environmental regulations have different impacts on industry competitive advantage. These effects may be a linear relationship (Song et al., 2018), threshold relationship (Xie et al., 2017), U-shaped relationship (Shuai and Fan, 2020) or inverted U-shape (Wang and Lin, 2018).

3. METHODOLOGY

3.1 Construction energy-environmental performance

The iron and steel industry in each province consumes capital, labor, and energy, abbreviated as K, L, E, respectively. The industry output value (Y) is taken as the desired output, and carbon dioxide emission (C) is deemed as an undesired output (Hu and Wang, 2006). Therefore, we can obtain the following environmental technology in the ISI :

$$T=\{(K,L,E,Y,C):(K,L,E)\ \ can\ produce\ (Y,C)\} \quad (1)$$

Referring to (Zhou et al., 2012), the energy-environmental performance index (EEPI) is constructed as follows:

$$EEPI=\frac{1-1/2(\beta_E^*+\beta_C^*)}{1+\beta_Y^*} \quad (2)$$

The energy-environmental performance index is the average energy use efficiency and pollution discharge efficiency. EEPI equals 1 means that the region's energy-environmental performance is on the optimal scale.

3.2 Tobit model

The Tobit model, proposed by (Tobin, 1958), is a regression model with restricted dependent variables. To effectively test whether environmental regulations have non-linear effects on the energy-environmental performance of ISI, we incorporate the squared term of regulation into the model. The Tobit model is set as follows:

$$EEPI_{it}=\alpha+\beta_1*ER_{it}+\beta_2*(ER_{it})^2+\sum_{i=1}^{I}r_i*X_{it}+u_i+\varepsilon_{it} \quad (3)$$

Where, $EEPI_{it}$ represents the energy-environmental performance in province i in year t. ER_{it} measures the environmental regulation in province i in year t. We identified three types of environmental regulations, namely, command-based, market-based, and public-based regulations. X_{it} is a set of control variables, including industrial structure, opening degree, capital structure, return on capital and energy structure.

3.3 Mediating effect model

We construct an analytical framework in which technological innovation is used as a mediator. A widely used test for the mediating effect is the stepwise method proposed by (Baron and Kenny, 1986). Three models are therefore constructed as follows.

$$EEPI_{it} = c * Regualtion_{it} + X_{it}^{*} + \varepsilon_{it} \quad (4)$$

$$Innovation_{it} = a * Regualtion_{it} + X_{it}^{*} + \varepsilon_{it} \quad (5)$$

$$EEPI_{it} = c^{'} * Regualtion_{it} + b * Innovation_{it} + X_{it}^{*} + \varepsilon_{it} \quad (6)$$

The meanings of variables and parameters are the same as those in Equation (3).

4. VARIABLES AND DATA SOURCES

This paper uses 29 Chinese provinces, autonomous regions and municipalities (hereafter provinces) from 2000 to 2017 as the research object. Because of data missing, Taiwan, Hong Kong, Macau and Tibet are not included in this study. We exclude Hainan province because its steel production is too small, and data is seriously missing. 2018 statistical yearbooks of some provinces are not yet published. For the accuracy of sample data, data of the year 2018 are not included in this paper.

We present descriptive statistics for all variables, as detailed in Table 1. The data are mainly from the China Statistical Yearbook, China Industrial Economy Statistical Yearbook, China Environment Yearbook and China Statistical Yearbook of Science and Technology.

Table 1 Summary statistics of the variables

Variable	Variable description	Mean	Std. Dev.	Min	Max
EEPI	Energy-environmental performance	0.32	0.18	0.09	1.00
MER	Market-based regualtion	0.00	0.00	0.00	0.01
MER2	Market-based regualtion	0.00	0.00	0.00	0.00
CER	Command-based regualtion	0.00	0.00	0.00	0.01
CER2	Command-based regualtion	0.00	0.00	0.00	0.00
PER	Public-based regualtion	0.36	0.28	0.00	1.64
PER2	Public-based regualtion	0.21	0.32	0.00	2.68
TI	Technical innovation	15.61	28.07	0.07	186.50
IS	Industrial structure	0.46	0.07	0.19	0.59
FDI	Foreign direct investment	125.7	157.68	0.18	934.00
CS	Capital structure	6.73	9.88	0.00	51.58
CPR	Cost-profit ratio	0.04	0.03	-0.07	0.15
ES	Energy structure	0.07	0.05	0.00	0.31

5. EMPIRICAL RESULTS AND DISCUSSION

5.1 Impact of environmental regulation on energy-environmental performance

We use Equation (3) to explore the non-linear influence of environmental regulation on energy-environmental performance. The estimation results of the Tobit model are presented in Table 2. Columns 1,3,5 are impacts of market-based, command-based and public-based environmental regulation on the efficiency performance, respectively. Columns 2,4,6 are results after adding control variables to columns 1,3,5.

We focus on results in Columns 2,4,6. Firstly, in terms of the environmental regulation type, the regression coefficients of primary terms of MER, CER and PER are significantly negative at the 1% level. It indicates that MER, CER and PER negatively impact the energy-environmental performance of ISI. However, the quadratic coefficients of MER, CER and PER are significantly positive. It means that the interaction between regulations and energy-environmental performance is not merely linear but U-shaped. As the environmental regulation intensity increases, the efficiency performance tends to fall and then rise.

We explain the U-shaped impact of different environmental regulations on environmental performance in detail in the full manuscript. The U-shaped relationship shows the existence of an ineffective interval of environmental regulation intensity. The inflection points of MER, CER and PER are 0.00332, 0.00492, 0.04086, respectively. According to the distribution of regulation intensity in Chinese provinces, most provinces are on the left of the inflection point. It indicates that environmental regulations hinder the efficiency performance of ISI. The Porter Hypnosis can be achieved if the regulation intensity is further enhanced in the long-term.

5.2 Estimation results of mediating model

Next, we use Equation (4)-(6) to examine the influence of environmental regulation on efficiency performance with technological innovation as the mediating variable. The results of mediating effects are shown in Table 3. Firstly, we examine the impact of

Table 1 Results of the Tobit model (national sample)

	MER		CER		PER	
	(1)	(2)	(3)	(4)	(5)	(6)
ER	-66.15***	-44.46***	-78.69***	-41.20***	-1.17**	-1.47***
	(6.986)	(7.413)	(8.037)	(8.711)	(0.567)	(0.477)
ER2	11,679***	6,698***	8,039***	4,186***	20.23**	17.99**
	(1,857)	(1,781)	(1,459)	(1,420)	(8.295)	(6.994)
TI		0.0020***		0.0020***		0.0027***
		(0.00029)		(0.00031)		(0.00028)
IS		-0.0422		-0.0625		0.0579
		(0.117)		(0.121)		(0.119)
FDI		0.00024***		0.00029***		0.00040***
		(0.0000)		(0.0000)		(0.0000)
CS		-0.0005		-0.0005		-0.0003
		(0.0014)		(0.0014)		(0.0014)
CPR		0.133		0.173		0.129
		(0.241)		(0.244)		(0.248)
ES		-1.049***		-0.905***		-0.923***
		(0.163)		(0.166)		(0.165)
Constant	0.284***	0.328***	0.304***	0.332***	0.304***	0.247***
	(0.016)	(0.059)	(0.017)	(0.060)	(0.023)	(0.059)
Inflection point	0.00283	0.00332	0.00489	0.00492	0.02892	0.04086
Wald test	89.75	232.04	98.19	217.97	6.14	199.88
	(0.000)	(0.000)	(0.000)	(0.000)	(0.046)	(0.000)
Observations	522	522	522	522	522	522
Number of provinces	29	29	29	29	29	29

Note: (i) Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. (ii) The p-value of the Wald test is reported in the table.

environmental regulation on energy-environment performance (Columns 1,4,7). It indicates a stable U-shaped relationship between environmental regulation and efficiency performance of ISI. We then estimate the effect of environmental regulation on innovation (Columns 2,5,8). It can be seen that MER, CER, PER also have a significant non-linear influence on technological innovation. Finally, we estimate the results of environmental regulation and technological innovation on efficiency performance (Columns 3,6,9). It demonstrates that the U-shaped effect of environmental *regulation on energy-environmental* performance is stable. Moreover, technological innovation has a significant positive impact on energy-environmental performance at the 1% level. In a word, the model demonstrates that environmental regulation influences energy-environmental performance by firms' innovation.

Innovation plays the U-shaped role between MER, CER PER and energy-environmental performance. As the environmental regulation intensity increases, its impact on technological innovation of ISI tends to fall and then rise. Only when the regulation intensity reaches a specific critical value (0.00136, 0.00626 and 0.02571) do firms face tremendous pressure to reduce CO2 emissions. It is difficult for firms to offset environmental regulation by increasing factor inputs, then firms invest in tec*hnological innovation to reduce the cost. At this time, firms* choose to invest in innovation, which generates innovation compensation effect and then forms a competitive advantage efficiency performance.

5.3 Estimated results of regional heterogeneity

Due to the different development levels in each region, there may be regional heterogeneity between environmental regulation and energy-environmental performance. In this section, Tobit random regression is conducted for three areas of China.

The estimation results are presented in the full manuscript. According to the results, we find that (1) For the eastern region MER and PER have significant U-shaped effects on EEPI. When the ISI faces higher MER and PER regulations, firms' incentive to meet environmental requirements is stronger. But the enhancement of CER intensity does not improve the efficiency performance. (2) For the central region, there is a U-shaped relationship between CER and EEPI. The Porter effect is only achieved when the CER intensity of

Table 3 Results of the influence mechanism

	MER			CER			PER		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	EEPI	TI	EEPI	EEPI	TI	EEPI	EEPI	TI	EEPI
ER	-64.72***	-140.26***	-44.46***	-67.36***	-210.41***	-41.20***	-1.22**	-17.29***	-1.47***
	(7.097)	(43.791)	(7.413)	(8.065)	(47.746)	(8.711)	(0.532)	(3.261)	(0.477)
ER2	10,143***	51,445***	6,698***	7,494***	16,800***	4,186***	18.75**	336.23**	17.99**
	(1,780)	(10,771)	(1,781)	(1,380)	(6,423)	(1,420)	(7.687)	(131.265)	(6.994)
TI			0.0020***			0.0020***			0.0027***
			(0.00029)			(0.00031)			(0.00028)
IS	-0.1652	4.3854***	-0.0422	-0.2105*	4.3794***	-0.0625	-0.0383	6.7538***	0.0579
	(0.121)	(0.706)	(0.117)	(0.124)	(0.728)	(0.121)	(0.131)	(1.144)	(0.119)
FDI	0.00007	0.00743***	0.00024***	0.00011	0.00668***	0.00029***	0.00018**	0.00814***	0.00040***
	(0.00008)	(0.00153)	(0.00008)	(0.00008)	(0.00154)	(0.00008)	(0.00009)	(0.00220)	(0.00008)
CS	-0.0008	-0.0044	-0.0005	-0.0008	-0.0063	-0.0005	-0.0016	-0.0260*	-0.0003
	(0.00146)	(0.01179)	(0.00135)	(0.00149)	(0.01174)	(0.00136)	(0.00165)	(0.01519)	(0.00140)
CPR	0.213	-3.344***	0.133	0.281	-2.780**	0.173	0.232	-3.361*	0.129
	(0.251)	(1.278)	(0.241)	(0.253)	(1.297)	(0.244)	(0.269)	(1.817)	(0.248)
ES	-1.449***	-3.962***	-1.049***	-1.250***	-3.687***	-0.905***	-1.534***	-6.960***	-0.923***
	(0.160)	(1.051)	(0.163)	(0.165)	(1.050)	(0.166)	(0.167)	(1.279)	(0.165)
Constant	0.454***	-0.541	0.328***	0.469***	-0.395	0.332***	0.408***	52.42***	0.247***
	(0.059)	(0.340)	(0.059)	(0.060)	(0.337)	(0.060)	(0.064)	(0.458)	(0.059)
Inflection point	0.00319	0.00136	0.00332	0.00449	0.00626	0.00492	0.03253	0.02571	0.04086
Wald test	179.83	112.92	232.04	167.73	106.34	217.97	96.11	220.78	199.88
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Observations	522	522	522	522	522	522	522	522	522

Note: (i) Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. (ii) The p-value of the Wald test is reported in the table.

ISI exceeds 0.00404. However, MER and PER do not impact the efficiency performance of ISI. (3) For the western region, MER and CER have a U-shaped effect on EEPI, which is largely consistent with the national sample results. But the residents' awareness of environmental protection in the western region is still weak, limiting the effect of PER.

6. ROBUSTNESS TEST

Energy-environmental performance and technology innovation are the core variables of this study. To verify the robustness, we replace the dependent variable and mediating variable to re-test it. This paper constructs an ECPI indicator to reflect efficiency performance with the study of (Zhang et al., 2014). For the mediating variable, the number of scientific researchers can also reflect firms' innovation ability. Therefore, we take scientific researchers to measure the firm's innovation behavior.

The estimation results are presented in the full manuscript. The results of the robustness tests are generally consistent with the basic results.

7. CONCLUSIONS AND SUGGESTIONS

7.1 Conclusions

Through empirical analysis, we come to the following conclusions. First, this paper supports the Porter Hypothesis in China's ISI at a certain regulatory intensity. There is a significant U-shaped relationship between MER, CER and PER and energy-environmental performance of ISI. Low environmental regulation intensity inhibits the improvement of efficiency performance. But with regulation intensity increases, it contributes to environmental improvement. Currently, the environmental regulation intensity in most provinces is on the left of the inflection point. The reality is that China's regulation intensity is still weak, and the Porter Hypothesis can only be achieved if the inflection point is exceeded.

Secondly, environmental regulation directly affects the energy-environmental performance of ISI and can also have a partial mediating effect through technological innovation. There is an influence mechanism of "environmental regulatio→technological innovation→energy-environmental performance."

Finally, there are obvious regional differences in the impact of environmental regulation on the energy-environmental performance of ISI in China. In the eastern region, there is a U-shaped relationship between MER, PER and EEPI, and a negative relationship between CER and EEPI. A significant U-shaped relationship exists between CER and EEPI in the central region. A win-win Porter effect can only be achieved when the intensity of CER exceeds 0.00404. In the western area, there is a significant U-shaped relationship between MER, CER and EEPI.

7.2 Policy suggestions

Firstly, it is necessary to make reasonable environmental regulations, not blindly pursue economic growth, and reduce the industry's regulation intensity. The study demonstrates that low regulation intensity is not effective in mitigating environmental pollution. It is only when environmental regulation intensity exceeds the inflection point that the energy-environmental performance of ISI can be truly improved. Therefore, it is necessary to increase the intensity of three types of environmental regulation.

Secondly, the ISI should accelerate the innovation system construction to promote industry upgrading. The study shows that technological innovation has a positive moderating effect on energy and environmental performance. It is essential to strengthening research, introduction and absorption of environmental technologies. Firms should invest more in green technologies to realize the mechanism of innovation for efficiency improvement.

Thirdly, it is essential to choose appropriate environmental regulations in different regions. The optimal combination of various environmental regulations can affect the environmental governance of ISI in different regions. Different areas of China have different economic development, technology level and natural resource endowment. When the government formulates environmental regulation policies, it should comprehensively consider the actual local situation based on these characteristics and enhance the regulations' applicability.

CONFLICTS OF INTEREST

We declare no conflict of interest.

ACKNOWLEDGEMENT

The paper is supported by the State Grid Corporation technology project (WBS No:521104170015), Report Series from Ministry of Education of China (No.10JBG013), and China National Social Science Fund (No.17AZD013).

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