What kind of technological innovation will be promoted by environmental regulation?

YaoJie Wu [1] **and ChunJie Chi** [1]

[1] Business Department, East China University of Science and Technology, Shanghai 200237, China

Abstract: According to the purpose of technological innovation, it is divided into process innovation and product innovation. Using the panel data of 30 provinces, municipalities, and autonomous regions in China from 2007 to 2016, we verify the impact of environmental regulation on process innovation and product innovation, and use threshold models to find that environmental regulation has threshold effects on process innovation and product innovation. The level of openness（*Open*） and foreign direct investment （*Fdi*） are threshold variables. The research results show that there are non-significant positive correlations between process innovation and product innovation in environmental regulation, among which the effect of environmental regulation on process innovation is central, western, and eastern; and the effect of environmental regulation on product innovation is eastern, western and central. Only when the level of openness （*Open*） is moderate, foreign direct investment（*Fdi*） is high, and environmental regulation has a role in promoting process innovation，the level of openness （*Open*） is of an inverted "U" type in process innovation. Only when foreign direct investment （*Fdi*） is moderate, environmental regulation promotes product innovation, the level of openness（*Open*） has no threshold effect on product innovation.

1. Introduction

High pollution and high economic growth are the experiences of every developed country. China is in the bottleneck of sustainable economic development. The huge economic level differences in the eastern, central and western regions make it more difficult for the government to formulate different environmental policies. The relationship between environmental regulation and technological innovation is a key link in whether environmental protection and economic development can be coordinated. According to Porter, when companies face environmental regulation, there are two forms of technological innovation [1]. The first innovative approach occurs in the production process, where companies suppress pollution emissions by making technological changes in their production lines or in end processing; and the second innovative approach can produce more refined new products through new designs and low-pollution. Scholars have gradually formed the concept of technological innovation in two different forms of process innovation and product innovation [2-5]. The former is to solve the problem of how to produce, and the latter is to solve the problem of production. Based on forms of technological innovation and regional differences, this paper studies the impact of environmental regulation on process innovation and product innovation, and combines the latest literature to study the linear relationship between environmental regulation and different forms of technological innovation methods, then discusses the environmental regulation through threshold effects whether to promote process innovation and product innovation under the influence of threshold

variables.

2. Literature review

After the Porter Hypothesis was put forward, most scholars supported the traditional view and denied the Porter hypothesis. Typical representatives are Jaffe and Palmer (1997)[6], Bhanagar and Cohen (2003)[7], Cesaroni and Arduini (2001)[8], who agreed that environmental regulation can significantly inhibit technological innovation in enterprises. Some scholars have also proposed different views to support the Porter Hypothesis. In the 1990s, Lanjouw and Mody (1996)[9], after 2000, Hamamoto (2006)[10] and Lanoie (2007)[11] proved the PH that environmental regulation would cause technological innovation in enterprises. But as the researches were promoted, scholars began to propose the so-called "uncertainty theory". For example, Ramanathan et al. (2017)[12] studied the impact of environmental regulation flexibility on technological innovation; Singh et al. (2017)[13] discussed the impact of environmental regulation in developed and developing countries on ELV innovation; Xie et al. (2017)[14] researched the relationship between different forms of environmental regulation on green productivity through the threshold effect; Lei et al. (2017)[15] developed the three-stage model, simultaneously using the threshold effect to analyze the non-linear effects and mechanisms of regulatory capture and regulation capabilities on environmental regulation benefits.

In summary, there is still a lack of in-depth research on two different forms of technological innovations in the field of environmental research. Only did Hu et al. (2017)[16] study the mediating effects of process innovation, product innovation on environmental regulation and business performance. This paper takes 300 samples from 30 provinces, municipalities and autonomous regions from 2007 to 2016 as samples to study the effects of environmental regulation on process innovation and product innovation in different regions. At the same time, further study on the environmental regulation under the influence of different threshold variables discusses the impact on process innovation and product innovation.

The rest of the paper consists of the following parts: the second part, research design, including model design, variable description, data source, etc.; the third part, empirical analysis; the fourth part, conclusions.

3. Model construction and data description

3.1 Panel regression model construction

Based on the model of Jaffe and Palmer (1997)[6], this paper establishes the linear models of environmental regulation for process innovation and product innovation in the industrial enterprises above designated size.

Process innovation regression model is as follows:

$$In(Process)_{i,t}=\beta_0 Er_{i,t-1} +\beta_1 Soe_{i,t} +\beta_2 Open_{i,t} +\beta_3 In(Hc)_{i,t} +\beta_4 In(Fdi)_{i,t} +\beta_5 In(Size)_{i,t}+ C +\varepsilon_{i,t} \quad (1)$$

Product innovation regression model is as follows:

$$In(Product)_{i,t}=\beta_0 Er_{i,t-1} +\beta_1 Soe_{i,t} +\beta_2 Open_{i,t} +\beta_3 In(Hc)_{i,t} +\beta_4 In(Fdi)_{i,t} +\beta_5 In(Size)_{i,t}+ C +\varepsilon_{i,t} \quad (2)$$

3.2 Panel threshold model construction

Based on the model established by Hansen (1999)[17], this paper establishes the threshold models of environmental regulation for process innovation and product innovation.

Process innovation threshold models are as follows:

$$In(Process)_{i,t}=\alpha_0 Er_{i,t-1}\cdot I(Open<\gamma_1) +\alpha_1 Er_{i,t-1}\cdot I(\gamma_1\leq Open\leq\gamma_2) +\alpha_2 Er_{i,t-1}\cdot I(Open>\gamma_2) + \alpha_3 Soe_{i,t} +\alpha_4 In(Hc)_{i,t} +\alpha_5 In(Size)_{i,t}+ C +\varepsilon_{i,t} \quad （3）$$

$$In(Process)_{i,t}=\alpha_0 Er_{i,t-1}\cdot I(In(Fdi)<\gamma_1) +\alpha_1 Er_{i,t-1}\cdot I(\gamma_1\leq In(Fdi)\leq\gamma_2) +\alpha_2 Er_{i,t-1}\cdot I(In(Fdi)>\gamma_2) +\alpha_3 Soe_{i,t} +\alpha_4 In(Hc)_{i,t} +\alpha_5 In(Size)_{i,t}+ C +\varepsilon_{i,t} \quad （4）$$

Product innovation threshold models are as follows:

$$In(Product)_{i,t}=\alpha_0 Er_{i,t-1}\cdot I(Open<\gamma_1) +\alpha_1 Er_{i,t-1}\cdot I(\gamma_1\leq Open\leq\gamma_2) +\alpha_2 Er_{i,t-1}\cdot I(Open>\gamma_2) +$$

EPPCT 2018

IOP Conf. Series: Earth and Environmental Science **199** (2018) 022003

IOP Publishing

doi:10.1088/1755-1315/199/2/022003

$\alpha_3 Soe_{i,t} + \alpha_4 In(Hc)_{i,t} + \alpha_5 In(Size)_{i,t} + C + \varepsilon_{i,t}$ （**5**）

$In(Product)_{i,t} = \alpha_0 Er_{i,t-1} \cdot I\ (\textbf{\textit{In(Fdi)}} < \gamma_1) + \alpha_1 Er_{i,t-1} \cdot I\ (\gamma_1 \leq \textbf{\textit{In(Fdi)}} \leq \gamma_2) + \alpha_2 Er_{i,t-1} \cdot I\ (\textbf{\textit{In(Fdi)}} > \gamma_2)$
$+ \alpha_3 Soe_{i,t} + \alpha_4 In(Hc)_{i,t} + \alpha_5 In(Size)_{i,t} + C + \varepsilon_{i,t}$ （**6**）

3.3 Variable Description

(1)*Process*: According to Hu et al. (2017) [16], this paper selects the technical renovation expenditure of industrial enterprises above designated size in various regions as a measure of process innovation.

(2)*Product*: According to Hu et al. (2017) [16], this paper selects the expenditure of new product development of industrial enterprises above designated size in various regions as a measure of product innovation.

(3)*Er*: This paper measures the environmental regulation of the operating cost of pollution control facilities per thousand yuan. The sum of the pollution control costs of waste gas and waste water in each region indicates the pollution control cost of each region.

(4)*Soe*: This paper selects the proportion of the total industrial output value of state-owned and state-controlled enterprises to the total output value of industrial enterprises above designated size to express the ownership structure.

(5)*Open*: This paper selects the total import and export volume of goods in each region (according to the location of the business unit) to account for the proportion of GDP in each region in the current year.

(6)*Hc*: This paper selects the full-time personnel equivalent of industrial enterprises above designated size to represent human capital.

(7)*Fdi*: This paper selects the actual amount of foreign investment in each region in the current year (US$10,000), and then converts it into 10,000 yuan according to the annual average exchange rate of RMB against the US dollar in each year.

(8)*Size*: This paper selects the ratio of the total industrial output value of industrial enterprises above designated size to the number of industrial enterprises above designated size to express the scale of the enterprise.

3.4 Data source

This paper selects 30 provinces, municipalities, and autonomous regions from 2007 to 2016(in which the Tibet Autonomous Region deletes the corresponding data due to the lack of data). The datum of process innovation and product innovation come from the China Science and Technology Statistical Yearbook, in which large and medium-sized industrial enterprises replaced large-scale enterprises in 2010 and 2007. The datum of environmental pollution control costs are derived from the China Environmental Statistics Yearbook. The datum of the total output value of industrial enterprises above designated size are not separately listed in the Statistical Yearbook from 2012 to 2016, and then some are extracted from the China Urban Statistical Yearbook (the sum of the industrial output value of cities above the prefecture level and the county level cities), others are extracted from the China Statistical Yearbook from 2007 to 2011. The datum of the ownership structure come from the China Statistical Yearbook, in which 2012-2016 is replaced by *the industrial added value of state-owned and state-controlled industrial enterprises/industrial added value of industrial enterprises above designated size*, coming from the China Industrial Statistical Yearbook. The datum of human capital and enterprise scale come from China Statistical Yearbook; the datum of foreign direct investment come from China City Statistical Yearbook.

4.Empirical analysis

4.1 Panel regression analysis

The sample data were subjected to quantitative regression analysis using Stata14.0. All models were tested by Hausman Test at 1% significance level, and all models used fixed effect models. As shown in Table 1.

(1) Process innovation

At the national level, the elasticity coefficient of environmental regulation is 0.0010, but it has not passed the significance test. From the analysis of different regions, the elasticity coefficient of environmental regulation in the eastern region is -0.0334. The elasticity coefficient of environmental regulation in the central region is 0.0178. The elastic coefficient of environmental regulation in the western region is 0.0170. Similarly, the three regions in the eastern, central and western regions have not passed the significant test. The results show that the positive correlation between environmental regulation and process innovation is mainly in the central and western regions, and the eastern region has a negative correlation. The compliance cost of environmental regulation in the eastern region is not compensated by the income of process innovation. Neither the country nor the three different regions have significantly indicated that they have not rejected the null hypothesis $\beta=0$. It can be inferred that environmental regulation has a nonlinear relationship to process innovation.

Table 1. Linear regression result

Region	National		Eastern		Central		Western	
	In(Process)	*In(Product)*	*In(Process)*	*In(Product)*	*In(Process)*	*In(Product)*	*In(Process)*	*In(Product)*
Er	0.0010	0.0066	-0.0334	0.0169	0.0178	0.0019	0.0170	0.0028
	(0.08)	(0.87)	(-1.50)	(1.52)	(0.70)	(0.12)	(0.73)	(0.19)
Soe	1.5648***	-1.5574***	1.9546	0.5102	3.2426**	-0.4734	-0.9051	-2.5583***
	(2.92)	(-5.03)	(1.65)	(0.86)	(2.58)	(-0.62)	(-1.05)	(-4.84)
Open	0.2733*	-0.1030	0.2021	-0.0549	2.5445	-1.3877	1.7540*	--0.4532
	(1.80)	(-1.18)	(1.08)	(-0.59)	(1.45)	(-1.31)	(1.74)	(-0.73)
In(Hc)	0.3575***	0.5261***	0.5431***	0.4949***	0.4269*	0.6437	-0.2272	0.6320***
	(4.24)	(10.81)	(4.95)	(9.03)	(1.83)	(4.55)	(-1.10)	(4.99)
ln(Fdi)	0.0518	0.0246	0.0096	0.1450*	0.0939	0.1227	0.0173	-0.021
	(0.82)	(0.67)	(0.07)	(1.98)	(0.48)	(1.03)	(0.22)	(-0.45)
In(Size)	-0.2598***	0.4530***	-0.3953***	0.4915***	-0.0092	0.3070	-0.1119	0.3935***
	(-2.99)	(9.03)	(-2.91)	(7.26)	(-0.04)	(2.35)	(-0.79)	(4.51)
C	8.7231***	8.2174***	7.5515	6.4135***	6.5260	5.3379	15.240***	8.1165***
	(6.32)	(10.33)	(2.76)	(4.69)	(1.56)	(2.10)	(6.48)	(5.13)

Note: 1.The numbers in parentheses are t values 2.*, **, *** respectively indicate passing the test at the level of significance of 10%, 5%and 1%.

(2) Product innovation

At the national level, the elastic coefficient of environmental regulation is 0.0066, but it has not passed the significance test. From the analysis of the three regions, the coefficient of environmental regulation in the eastern region can be found to be 0.0169, and counterparts in the central region and western region are respectively 0.0019 and 0.0028. Similarly, the three regions still fail the significance test. The research results show that environmental regulation is positively related to product innovation, but it is not significant. The degree of influence in each region from east to west is east, west and middle. Although the innovation compensation brought by product innovation is greater than the cost of compliance, it is not significant, which indicates that the national and three regions have not rejected the null hypothesis $\beta=0$, inferred that there is a nonlinear relationship between environmental regulation and product innovation.

4.2 Panel threshold analysis

Combined with the Xthreg model written by Wang (2015)[18], the following conclusions can be drawn from the threshold test of samples from 30 provinces, municipalities and autonomous regions in China from 2007 to 2016. As shown in Table 2, the conclusion is drawn:

Table 2. Threshold variable test and threshold estimation

	Threshold variable	Model	F value	Threshold estimate
Process	*Open*	Single	16.00**	1.1402
		Double	20.37***	1.0487 1.2302
	In(Fdi)	Single	14.19*	12.9448

		Double	7.67	12.9448 14.7802
	Open	Single	12.73	1.5093
		Double	8.47	1.5093 0.0712
Product		Single	7.44	11.5543
	In(Fdi)	Double	16.39*	13.0881 13.1118

Note: *, **, *** respectively indicate passing the test at the level of significance of 10%, 5%, and 1%.

The degree of openness in process innovation（*Open*） is a double threshold with thresholds of 1.0487 and 1.2302 respectively. Foreign direct investment in process innovation（*Fdi*） is a single threshold with a threshold of 12.9284. Foreign direct investment in product innovation（*Fdi*） is a double threshold with thresholds of 13.0881 and 13.1118 respectively. There is no threshold effect on the degree of openness in product innovation（*Open*）.

As shown in Table 6, the threshold regression results indicate:

Table 3.Threshold regression result

Variable	*Open* Process	*In(Fdi*） Process	Product
Soe	1.1710*** (2.68)	1.2541*** (2.80)	-1.6173*** (-6.18)
In(Hc)	0.2764*** (3.30)	0.3853*** (4.67)	0.5339*** (10.67)
In(Size)	-0.2366*** (-3.04)	-0.3038*** (-4.02)	0.4669*** (10.40)
Er_1	0.0478 (0.38)	-0.0107 (-0.79)	0.0083 (1.03)
Er_2	0.1764*** (5.04)	0.0493*** (2.08)	0.0486** (2.02)
Er_3	-0.0127 (-0.30)		-0.082 (-0.72)
C	10.4877*** (12.08)	9.3159*** (10.69)	8.5039*** (16.13)

Note: 1.The numbers in parentheses are t values 2.*, **, *** respectively indicate passing the test at the level of significance of 10%, 5%, and 1%.

（1）Process innovation

When *Open* is less than 1.0487, the elastic coefficient of environmental regulation for process innovation is 0.0478, but it fails the significance test. When *Open* crosses the low threshold but not more than 1.2302, the elastic coefficient of environmental regulation for process innovation is 0.1764, which was significant at the level of significance of 1%. It can be concluded that the degree of openness （*Open*）is inverted U-shaped. Under the effect of openness（*Open*）, environmental regulation promotes post-inhibition of process innovation, and when the degree of openness（*Open*） is between 1.0487 and 1.2302, environmental regulation is significantly positively related to process innovation.

When *In(Fdi)* is less than 12.97448 (*Fdi*<418653.97 ten thousand yuan), the elastic coefficient of environmental regulation for process innovation is -0.0107, but the significance test is not passed, but when *In(Fdi)* is not less than 12.9744 (*Fdi*≥418653.97 ten thousand yuan), the elastic coefficient of

environmental regulation for process innovation is 0.0493, which was significant at the 1% level of significance. It can be concluded that when foreign direct investment（*Fdi*）is at a high threshold (*Fdi* ≥ 418653.97 ten thousand yuan), environmental regulation is significantly positively related to process innovation.

（2）Product innovation

When *In(Fdi)*< 13.0881 (*Fdi*<483158.48 ten thousand yuan), the elastic coefficient is 0.0083, but it did not pass the significance test. When *In(Fdi)* is within the range of [13.0881,13.1118] (483158.48≤ *Fdi* ≤494746.11 ten thousand yuan), it passes the test at 5% level of significance and the elastic coefficient of environmental regulation for product innovation is 0.0486. When *In(Fdi)* is at a high threshold (*Fdi*>494746.11 ten thousand yuan), the elastic coefficient is negative and does not pass the significance test. It can be concluded that foreign direct investment （*Fdi*）is inverted U-shaped, and when it is at a moderate threshold (483158.48≤ *Fdi* ≤494746.11 ten thousand yuan), environmental regulation has played a role in technological spillovers for product innovation.

5.Conclusion

Based on the panel data of 30 provinces, municipalities and autonomous regions in China from 2007 to 2016, this paper studies the linear effects and thresholds of environmental regulation on process innovation and product innovation of industrial enterprises above designated size, and draws the following conclusions: (1) Environmental regulation has a non-linear relationship between process innovation and product innovation, whether at the national level or in three different regions of the eastern, central and western regions. The role of environmental regulation in process innovation is respectively in the central, western and eastern regions, and the role of environmental regulation in product innovation is respectively in the east, west and central. (2) The degree of openness（*Open*）is inverted U-shaped in process innovation. Under the effect of openness（*Open*）, environmental regulation promotes post-inhibition of process innovation. When the degree of openness （*Open*）is between 1.0487 and 1.2302, environmental regulation is significantly positively related to process innovation. When foreign direct investment（*Fdi*）is at the high threshold (*Fdi*≥418653.97 ten thousand yuan), environmental regulation is significantly positively related to process innovation.（3）Foreign direct investment（*Fdi*）is inverted U-shaped in product innovation. When it is at the moderate threshold (483158.48≤ *Fdi* ≤494746.11 ten thousand yuan), environmental regulation has played a role in technological spillovers for product innovation; and for product innovation, there is no threshold for openness（*Open*）.

References

[1] M.E Porter, C Van der Linde. *Toward a new conception of the environment － competitiveness relationship* .JEP, **9**, 4(1995)

[2] Adner, Ron, Levinthal, Daniel. *Demand heterogeneity and technology evolution: implications for product and process innovation*. MS, **47**,5(2001)

[3] Fondas, Nanette. *Process innovation: reengineering work through information technology*. EJIS,**3**,3(1994)

[4] Danneels, Erwin. *The dynamic of product innovation and firm competences*. SMJ,**23**,12(2002)

[5] H.Y Li, Atuahene-Gima, Kwaku. *Product innovation strategy and the performance of new technology ventures in China*. AMJ, **44**,6(200)

[6] A.B Jaffe, K. Palmer *Environmental regulation and innovation: A panel data study*.RES,**79**,4(1997)

[7] S.B Brunnermeier, M.A Cohen. *Determinants of environmental innovation in US manufacturing industries*.JEEM,45,2(2003)

[8] F Cesaroni, R Arduini .*Environmental Technology in the European Chemical Industry*. LEM,(2001)

[9] J.O Lanjouw, A. Mody. *Innovation and the international diffusion of environmentally responsive*

   *technology.*RP,**25**,4(1996)

[10] M Hamamoto. *Environmental regulation and the productivity of Japanese manufacturing industries*.REE,**28**,4 (2006)

[11] P Lanoie, S Ambec, L Scott W*hen and Why Does it Pay to be Green?*. CDR(2007)

[12] Ramanathan R, He Q, Black A, Ghobadian A, Gallear D. *Environmental regulations, innovation and firm performance: A revisit of the Porter hypothesis*.JCP,**55**(2017)

[13] R.K Singh et al. *Comparative study of linkage between environmental policy instruments and technological innovation: Case study on end-of-life vehicles technologies in Japan and EU*.WM,**66**(2017)

[14] R.H Xie ,Y.J Yuan, J.J Huang. *Different Types of Environmental Regulations and Heterogeneous Influence on "Green" Productivity: Evidence from China*. EE, **132**(2017)

[15] P Lei, P Huang, D.Y He Determinants and welfare of the environmental regulatory stringency before and after regulatory capture. JCP, 106(2017)

[16] D Hu, YD Wang, J.S Huang, H.Y Huang. *How do different innovation forms mediate the relationship between environmental regulation and performance?*. JCP,161(2017)

[17] B.E Hansen. *Threshold effects in non-dynamic panels: Estimation, testing, and inference*. JE, **93**,2(1999)

[18] Q Wang. *Fixed-effect panel threshold model using Stata*.SJ,**15**,1(2015)