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ARTICLE

Research on the effects of command-and-control and market-oriented policy tools on China's energy conservation and emissions reduction innovation

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ABSTRACT
The impact of environmental regulation on technology innovation is a hot spot in current research where a large number of empirical studies are based on Porter Hypothesis (PH). However, there are still controversies in academia about the establishment of "weak" and "narrow" versions of PH. Based on the panel data of application for patent of energy conservation and emission reduction (ECER) technology of Chinese city scale during 2008–2014, comprehensive energy price, pollutant emission, etc., mixed regression model and systematic generalized method of moments method were adopted, respectively, to study the impact of market-oriented and command-and-control policy tool on China's ECER technology innovation. The results show that the environmental regulation hindered the technological innovation in the immediate phase; however, it turned out to be positive in the first-lag phase. Hence, the establishment of "weak" PH is time-bounded. The command-and-control policy tool played a more positive role in promoting technological innovation in the first-lag phase than market-oriented policy tool. Therefore, "narrow" PH is not tenable. The reason is that the main participants of China's ECER technology innovation are state-owned companies and public institutions. Regionally speaking, the impact which command-and-control policy tool has on technological innovation at sight was non-significant in the eastern, the central, and the western regions of China whilst market-oriented policy tool had a negative effect. And market-oriented policy tool in the central region had strongest negative effect, which would diminish in the eastern region and become weakest in the western region. This was related to regional energy consumption level and the market economic vitality.

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1. Introduction

How to fulfill the win-win situation of economic development and environmental protection in developing country is a question under discussion. As the participant and main role in the action of ECER, companies have always failed to take their social responsibility of environment protection when searching for the development of companies, which calls for suitable environmental regulations. Environmental regulation refers to direct and indirect intervention of government on environmental polluting action in order to control pollution or improve ecological environment. The approaches include imperative way as administrative regulation and market-oriented type as economic means (Huang et al. 2015). China is currently undergoing a period of slowing down of economic acceleration and deepening of structure adjustment, which leaves environmental regulations in a total different economic background from the past. Under this situation, fully applying environmental regulations, promoted by innovation to pursue technology innovation, is a matter of utmost importance.

Since the carrying out of the Eleventh Five Year Plan (2006–2010) by Chinese government, strength had been focused on reinforcing policy restrictions on fossil energy consumption and greenhouse gas emission. The state council successively released *Notice of the State Council on Issuing the Comprehensive Working Program on Energy Conservation and Emission Reduction (State of Council Document No. 15 of 2007), Comprehensive Working Program on Controlling Greenhouse Gas Emission of the Twelfth Five Year Plan (State of Council Document No. 41 of 2011)*, and *The Twelfth Five Year Plan on Energy Conservation and Emission Reduction (State of Council Document No. 40 of 2012)*, where it proposed ECER measures such as reinforcing index control, strengthening supervision, adjusting industry structure, developing energy-conservation technology, and developing and perfecting economic policy. In 2015, President Xi Jinping had made a pledge in the international climate talks in Paris that China would accomplish 60–65% decrease in Carbon Dioxide Emission per

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Unit of Gross Domestic Product in the year of 2030 compared to 2005 levels and develop the road-map of ECER by then. During the evolving of environmental regulation policy system, economic approaches like market-oriented mechanism have gradually caught the attention of the public. In the year 2013, China was launching seven regional pilot emissions trading systems in Beijing, Shanghai, Guangdong Province, Shenzhen, Tianjing, Chongqing, and Hubei Provinces. And it is initiating a national carbon emissions trading system in 2017, which is currently the largest market-oriented environmental regulation practice in China (Wang and Qi 2016).

However, questions like whether environmental regulation can provoke innovation and in which way it can provoke innovation have become the focus of innovation research area. There were massive empirical researches based on PH devoting in searching answers while it has not reach consensus among them. This paper adopts data of ECER patent, pollutant emission, energy consumption, and energy price from 285 prefectural-level municipalities in China ranging from 2008 to 2014 to search the influence of different environmental regulation approaches on ECER innovation. This paper includes the following parts: in the second part, literature review based on PH is firstly mentioned and focused on the answer of whether "narrow" PH and "weak" PH fits for the environmental innovation of China. In the third part, environmental regulations' Induced Effect Model on ECER innovation is constructed with illustration on the selection of each index, calculation procedure, and data source in the Model. And the fourth part is about calculation results and analysis while the main conclusion is drawn in the fifth part.

2. Literature review

Porter and Van first illustrated that the proper environmental regulation could induce environmental protection and competitiveness through theory and case studies and put forward the PH. Jaffe and Palmer (1997) further elaborated the PH into "strong" PH, "weak" PH, and "narrow" PH. "Strong" PH emphasizes that environmental regulation can enhance the competitiveness of companies while "weak" PH suggests that environmental regulation can stimulate company innovation. And "narrow" PH emphasizes that flexible market policy tools can stimulate company innovation more than command-and-control type regulation. This paper mainly verifies the "narrow" and "weak" PHs to study the direct relationship between environmental regulation and company innovation rather than company competitiveness.

Scholars still debate over the tenability of "weak" PH and "narrow" PH (Lanoie et al. 2008; Zhang et al. 2011; Shen and Liu 2012; Ambec et al. 2013; Rexhaeuser and Rammer 2014; Yu and Chen 2015). There are three main points about "weak" PH: ① Environmental regulation promotes technological innovation. Scholars such as Brunnermeier and Cohen (2003) and Hamamoto (2006) have concluded that the pollution control costs and environmental patents have positive correlation after empirical research on manufacturing industry in the US and Japan. ② Environmental regulation inhibits technological innovation. On the basis of the empirical study of German manufacturers, Wagner (2007) pointed out that environmental management level is negatively correlated with company patent application. Chintrakarn (2008) also argued that strict environmental regulations in America are hindering technological advancement of manufacturing field. ③ The relationship between environmental regulation and technological innovation is uncertain. Chinese scholars represented by Jiang et al. (2014) adopted generalized method of moments (GMM) method in the panel data analysis of manufacturing industry in Jiangsu Province in 2004–2011 and pointed out that the relationship of environmental regulation and company technology innovation is featured with "U" type of dynamic characteristics with a decline followed by increase. In addition, a few scholars abroad compared the influence of different policy tools for innovation in order to test and verify "narrow" PH; it results in two opposing views: ① Market-oriented environmental regulation tools for innovation are stronger than the effect of command-and-control type. Popp (2003) found that adopting the SO_2 trading emission system was more effective than the direct control of technical standards implementation. The command-type environmental regulation tools have a stronger effect on innovation than the market-oriented type. Some scholars, such as Testa et al. (2011), pointed out that direct control has a positive impact on company innovation while economic means have a negative impact.

As mentioned above, the study of "weak" and "narrow" PHs has not reached consensus among scholars, which calls for further discussion. What's more, current case studies of China are mainly based on provincial panel data or specific region. The disadvantages of these studies are that research unit is either oversize, leading to the low accuracy and low credibility of the calculation results (34 provincial administrative region) or single research unit ends with research conclusion of high speculative and contingency. This paper chose the prefecture-level city scale to reasonably reflect the relationship between China's environmental innovation and regulation. In addition, China is a country with vast territory and featured with relative obvious difference in economic development level, technology level, and governance capabilities between eastern, central and western regions. Comparing the effect of environmental regulation on technology innovation between these regions contributes to promoting the efficiency of the regional environment. However, there are few studies focusing on the regional heterogeneity of different regulatory tools effects on technological innovation. Based on China's 285 prefecture-level panel data, this paper, in other words, is devoted in analysis of the influence of market-oriented type and command-and-control type environmental regulation tools on China's ECER technology innovation.[1]

3. Model construction, variable selection, and processing

3.1. Mechanism of environmental regulation tools on technological innovation of ECER

Market-oriented environmental regulation tools are characterized by setting prices on emissions and affect the decisions of polluters in carbon tax and carbon emissions trading by sending market signals such as price, taxes, fees and subsidies, and credit. However, China has not achieved long-term implementation of carbon trading policy across the country. Due to the lack of data, this paper references the mapping method carbon price invented by scholars represented as Cullen and Mansur (2017), where carbon price is regarded as the price markup of energy prices and used to estimate the induced effect of market-oriented environmental regulation tools on technology innovation of ECER. The aim of market policy tool is to produce an exogenous markup on the basis of energy price to regulate the carbon emission. The larger the energy consumption of companies, the greater the cost pressure and economic stimulation of the energy price. Therefore, the company may save the cost by improving the technology innovation of ECER.

The command-and-control type of environmental regulation tools mainly refers to the direct control by the government. The government restricts the pollution discharge of companies by enforcing environmental standards, setting emission quotas, and other strict control methods. Direct control increases the cost of pollution control in companies, which may stimulate companies to make innovations in ECER technologies. A variety of indicators has been used to measure the intensity of command-and-control environmental regulations in previous researches. For example, Wang Banban and others scholars adopted the goal of energy reduction of the industry in government documents. Many scholars graded the intensity of ECER policy in China (Feng et al. 2017). Domazlicky and Weber (2004), Jiang et al. (2014), Huang et al. (2015), and other scholars pointed out that the higher the pollution emissions, the stricter the government control. Instead, they adopted different pollutant emissions intensity as metrics. Based on the data availability of prefecture-level city scale, this paper uses the comprehensive index of pollution emission to measure the intensity of urban command environment regulations.

From the perspective of mechanism, the performing of environmental regulations depends on the effectiveness of government to implement these policies and exert noticeable cost pressures and economic stimulation toward companies. Since companies pursue the maximization of profit, companies, under stringent environmental regulations, will devote efforts in technical innovation to improve the production process or improve anti-pollution ability and eventually slow or offset the environmental markup costs of environmental regulations so as to reduce the pollution brought by command-and-control type environmental regulation tools cost rise and market-oriented environmental regulation tools of rising energy costs, which is known as innovation compensation effect of environmental regulations.

To sum up, this paper constructed the technological innovation induced effect model of market-oriented type and command-and-control environment regulation tools:

$$patent_{it} = \beta_0 + \beta_1 price_{it} + \beta_2 ER_{it} + X_{it}b + \mu_i + \eta_i + \varepsilon_{it} \quad (1)$$

i refers to region, t refers to time, $patnet_{it}$ refers to the number of patents, $price_{it}$ means the energy price index, and ER_{it} refers to pollution emission composite index. X_{it} means control variables, μ_t and η_i refers to non-observation effects of time and region, respectively, and ε_{it}means stochastic error term.

Due to the path dependence effect of technological innovation, there may be certain lag in the effect of environmental regulations (Wang and Wang 2011; Chen et al. 2016). In order to reflect the early accumulation of technological innovation, the influence of market-oriented and command-and-control type of environmental regulation measures on the current command type, we set up a dynamic panel data model of first lag phase, and adopted systematic GMM as estimate method

$$patent_{it} = \beta_0 + \beta_1 patent_{it-1} + \beta_2 ER_{it-1} + \beta_3 price_{it-1} + X_{it} b + \mu_i + \eta_i + \varepsilon_{it} \quad (2)$$

3.2. The selection of data variation and processing

(1) Patent of ECER. Searching within the Public Patent Database Retrieval System under Shanghai Intellectual Property Information Platform (www.shanghaiip.cn/Search/login.do), we retrieve invention patent and ECER technologies (compared to the utility model patent and design patent, invention patent is considered as highest in innovation level). The patents were divided according to the year of their application date. Since 2008, the number of patents on ECER has accelerated significantly (Figure 1). We shall notice that the procedure of patent application to final audit takes 18 months. Since patents data in the period of 2014 is complete, this study selected time span from 2008 to 2014 and the retrieval was accomplished from August to October 2016 with a total of 90,099 patents. After excluding the patent applied by foreign organizations, the remaining quantity is 87,066. After searching within China post code enquiry website (www.youbianku.com), we found there are 33,847 zip codes in all regions of the country and thereafter established the postal code base. Then the postcode of the patent contact address was matched with the information of the postcode and categorized according to the statistics of the prefectural-level municipalities and produced the number of patent applications of ECER of each prefectural-level municipalities applied each year.[2] Table 1 shows list of the top 50 companies in patent quantity of ECER technology application. It can be seen that energy and pollution-intensive industry such as oil, steel, metal processing industry, and strategic emerging industry such as new energy industry, new IT industry pay more attention to develop green technology.

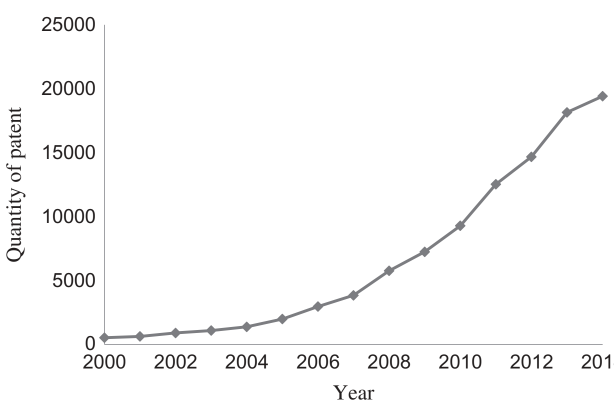

Figure 1. Trend of China's patent application of ECER technology during 2000–2014.

(2) Intensity of command-and-control environmental regulations. The comprehensive index of pollutant emission in each municipality was calculated to represent the intensity of order environmental regulations in each municipality. The calculation steps are as follows:

①Linear standardization of the discharge of pollutants in each city. This paper mainly calculated three kinds of pollutants, such as waste water, SO_2, and smoke. The data came from the *China City Statistical Yearbook*.

$$UE^s_{ij} = \left[UE_{ij} - MINUE_j\right] / \left[MAX\left(UE_j\right) - MIN\left(UE_j\right)\right] \quad (3)$$

In details, UE_{ij} refers to the quantity of pollutant, j discharged per unit pollutants output value in i city, $MAX\left(UE_j\right)$ and $MIN\left(UE_j\right)$ refer to the maximum and minimum value of different index in each city, and UE^s_{ij} is the standardized value of indicators.

②The emission intensity of pollutants in different cities varied greatly so is the emission intensity of different pollutants. The adjustment coefficient was used to approximate the characteristics of pollutants. The adjustment coefficient formula is:

$$W_j = UE_{ij} / \overline{UE_{ij}} \quad (4)$$

$\overline{UE_{ij}}$ means the average level of urban emission per unit of pollutant j emitted during the sample period.

③ Calculation of intensity of command-and-control environmental regulations of each city. ER refers to command-and-control environmental regulations of each city

$$ER_i = \frac{1}{3} \sum_{j=1}^{3} W_j UE^s_{ij} \quad (5)$$

(3) Intensity of market-oriented environmental regulations. The city comprehensive energy price index was calculated to represent the city's market-oriented environment regulation intensity. China has not yet announced comprehensive energy price. Some scholars had used the

Table 1. The list of top 50 companies in the quantity ECER patent application during 2008–2014.

Rank	Enterprise of patent application	Quantity of patent	Rank	Enterprise of patent application	Quantity of patent
1	State Grid Corporation of China	360	26	Dalian Trandar Technology Trading Market Co., Ltd	57
2	Liuzhou Jingyang Energy Saving Technology Co., Ltd	315	27	Shenyang Aluminum and Magnesium Design and Research Institute Co., Ltd.	55
3	Zhongxing Telecommunication Equipment Corporation	303	28	Guangdong Midea Refrigeration Equipment co., Ltd	54
4	Huawei Technologies Co Ltd	254	29	Ansteel Co., Ltd	52
5	China Petroleum and Chemical Co., Ltd	213	30	Xi'an Boyu New Energy Co., Ltd.	52
6	Hong Fujin Precision Industry Shenzhen Co., Ltd	206	31	Xi'an Dayu Optoelectronics Technology Co., Ltd	51
7	Qingdao Wangli Technology Co., Ltd	179	32	WISDRI Engineering and Research Co., Ltd	51
8	Zhuhai Gree Electric Appliance Co., Ltd	145	33	Wuxi Little Swan Co., Ltd	48
9	Kunshan Fuling Energy Utilization Co., Ltd	135	34	Baowu Steel Group Co., Ltd	48
10	Kunshan Bowen Lighting Technology Co., Ltd	130	35	Guizhou Guangpu Sen photoelectric Co. Ltd	47
11	Green Technology Construction Group Co., Ltd	120	36	BOE Technology Group Co., Ltd	45
12	Haier Group	106	37	Aluminum Corporation of China Limited	45
13	Kunshan Shengguang Energy Technology Co., Ltd	99	38	Harbin Yongheng Xin Technology Development Co., Ltd	44
14	Harbin Hongtian RuiDa Technology Co., Ltd	85	39	CISDI Engineering Co., Ltd	44
15	Chongqing LeEr Jia Machinery Co., Ltd	81	40	Shenyang Trandar Technology Trading Co., Ltd	43
16	Lenovo (Beijing) Co., Ltd.	77	41	Suzhou Gold Mantis Curtain Wall Co,Ltd	42
17	Inspur Electronic Information Industry Co., Ltd	73	42	Guangdong Shenling Air Conditioning Equipment Co., Ltd	41
18	Qingdao Tongchuang Energy Saving and Environmental Protection Engineering Co., Ltd	72	43	Xuyi County Dongqiang New Building Materials Factory	41
19	Guangxi Tianyuan Biochemistry Co., Ltd	69	44	Guangdong Midea Electric Appliance Co., Ltd	40
20	Baoshan iron and steel Co. Ltd	66	45	Konka Group Co., Ltd	40
21	PetroChina Co., Ltd	64	46	Ningxia Xinhang Energy Technology Co. Ltd	40
22	Kunshan Fuling Kitchen co., LTD	62	47	Zoomlion GmbH & Co. Kg	40
23	Oceansking Lighting Science & Technology Co., Ltd.	61	48	Chery Automobile Co., Ltd	39
24	Ningxia Qikai Energy-Saving Equipment Co., Ltd	60	49	Huizhou TCL Mobile Communications Co., Ltd	37
25	Qingdao Ultimate Energy Conservation and Environmental Protection Co., Ltd	59	50	Nantong Xinying Design Service Co., Ltd	37

national overall indicators such as industrial producers purchasing price index and producer price index for alternative. Unfortunately, they missed out regional energy consumption structure and actual energy price difference. This study refer to the methods of scholars like Ma et al. (2008), Wang and Qi (2016), and other scholars to calculate the comprehensive energy price of the region. ①*Prices Yearbook of China* published prices of coal, gasoline, diesel, and electricity in 36 large and medium cities each year (four types of energy consumption of total energy consumption accounted for major proportion. According to the *2015 China Statistical Yearbook*, coal accounted for 66% of total energy consumption, and oil accounted for 17.1% of total energy consumption). The average prices of each type of energy, respectively, each year were included and sequence-extended based on the producer price index of coal mining and mineral processing industry, oil and gas exploration industry, electricity and heat production, and supply industry, which was finally adjusted based on the benchmark price of 2008. ② The *China Energy Statistical Yearbook* releases four types of energy consumption per year in every province. We assigned weights to corresponding energy price and estimated the energy costs of the provinces accordingly. ③ Dividing the total energy consumption provinces by the provincial energy cost, we got the regional comprehensive energy prices. (Since there were no energy consumption statistics of prefecture level municipalities available and there were minor differences of energy price between each city in the province, the comprehensive energy price of prefecture-level municipalities was replaced by the relevant provincial data.)

(4) Control of variables. ①Economic openness (Foreign Direct Investment) is represented by the proportion of output value of foreign invested companies in total industrial output. The entry of foreign capital can make up for the shortage of local capital and bring in advanced technology and stimulate the innovation of local companies through demonstration, competition, personnel training and turnover. ② R&D per capita. Based on the benchmark data of 2008, the index of per capita GDP was sequential-expanded. R&D investment shall provoke the innovation output. ③Economic development level. Measured by per capita GDP

(Wang and Wang 2011) and used the same price calculation method as per capita R&D. ④ Region variables. Three virtual variables were introduced as control variables of region. Respectively, E (E = 1 represents that city locates in the eastern region, E = 0 that the city is not from eastern region), W (W = 1 represents that city locates in the western region, W = 0 that the city is not from western region), and C (C = 1 shows that the city locates in the central region, C = 0 means that the city is not from the central region). Mixed regression model was used to estimate three major economic zones to compare technology innovation effect of different regional regulation tools. In order to differentiate the influence degree of various factors, the deviation of patent, energy price, and control variables were standardized. The data comes from the *China Statistical Yearbook* and the *China City Statistical Yearbook*. And the definition of variables shows in Table 2.

4. Empirical analysis and results discussion

4.1. Spatial differences between the technological innovation of ECER and the intensity of environmental regulations

From the average value of each variable in period of 2008–2014 (Table 3), the technological innovation of ECER was the highest in the eastern region and the western region qualified the second and the central region was the lowest. The command-and-control environmental regulations showed the highest intensity in the western region and the lowest in the eastern region. The market-oriented environment regulation in the eastern region was higher than the western region and the lowest in the central region. Taking the year of 2014 as an example, the patent, pollution, and energy prices showed significant spatial differences between cities. Judging from the patent quantities (Table 4), Shandong peninsula, Beijing and Tianjin, Yangtze River delta, Chengdu-Chongqing region showed higher level in ECER technology, whereas Beijing, Suzhou, Qingdao, Shanghai, Tianjin were ranked as top five. Yunnan Province, the central region of Shaanxi Province, and most of the central region were relatively low in technical level of ECER and Lijiang, Pu Er, Lincang, Tongchuan, and Ankang were the lowest. From the pollution composite index (Table 5), Shanxi Province, Inner Mongolia, Shaanxi Province, Heilongjiang Province, Yunnan Province, Gansu Province, and other parts in the midwest region were serious in pollution and thus under higher intensity in command-and-control type of environmental regulation. Jinchang, Hechi, Baiyin, Fuxin, Jiayuguan ranked top five in pollutant emission; Bazhong, Ziyang, Sanya, Changsha, and Shenzhen were among the last five from bottom. Based on the synthetic energy price index (Table 6), the Pearl River delta, Yangtze River delta, Yunnan Province, Inner Mongolia were higher in energy prices and stronger in market-oriented environmental regulation intensity. Hebei Province,

Table 2. Definition of variables.

Variable types	Variable	Meaning of variable
Dependent variable	patent	Patent quantity of ECER of each city
Independent variable	ER	comprehensive index of pollutant emission
	price	Comprehensive energy price index
	lag(ER,1)	Comprehensive pollutant emission index a year lagging
	lag(price,1)	Comprehensive energy price index a year lagging
	lag(patent,1)	Patent application quantity of ECER a year lagging
Control of variables	FDI	The proportion of output value of foreign invested companies in total industrial output
	R&D	R&D investment per capita
	GDP	Domestic GDP per capita
	region	Regional control of variables

Table 3. Descriptive statistical characteristics of variables.

	Eastern region			Central region			Western region		
Variable	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max
Patent(quantity)	85	0	1350	19	0	356	21	0	655
ER	0.02245	0.00001	1.08118	0.19745	0.00025	41.30026	0.21084	0.00018	24.34680
Price	1,936	1,289	2,482	1,831	1,368	2,239	1,856	1,285	2,354
FDI (%)	14.2	0.4	51.9	5.6	0	48.1	4.6	0	51.0
R&D (RMB)	163	5	3210	51	2	626	36	2	328
GDP (RMB)	39,061	10,050	312,018	26,138	6,475	171,353	20,912	3,602	149,757

Table 4. The rank of emission reduction technology innovation at prefecture-level in 2014.

Top 25			Last 25		
Province	City	Quantity of patent	Province	City	Quantity of patent
Beijing	Beijing	1,350	Jilin	Hakusan	2
Jiangsu	Suzhou	1,125	Jilin	Tonghua	2
Shandong	Qingdao	980	Inner Mongolia	Bayannur	2
Shanghai	Shanghai	806	Sichuan	Guang'an	2
Tianjin	Tianjin	627	Sichuan	Dazhou	2
Jiangsu	Nanjing	518	Henan	Luohe	2
Jiangsu	Wuxi	482	Shaanxi	Yan'an	2
Shaanxi	Xi'an	475	Jilin	Matsubara	2
Sichuan	Chengdu	464	Jilin	Baicheng	1
Guangdong	Shenzhen	411	Heilongjiang	Heihe	1
Guangdong	Guangzhou	400	Gansu	Longnan	1
Zhejiang	Hangzhou	368	Liaoning	Fuxin	1
Anhui	Hefei	356	Ningxia	Guyuan	1
Heilongjiang	Harbin	343	Gansu	Dingxi	1
Chongqing	Chongqing	338	Jiangxi	Yingtan	1
Zhejiang	Ningbo	331	Yunnan	Zhaotong	0
Hunan	Changsha	321	Heilongjiang	Hegang	0
Hubei	Wuhan	288	Yunnan	Lijiang	0
Shandong	Jinan	280	Yunnan	Baoshan	0
Guangdong	Foshan	269	Shaanxi	Ankang	0
Guangxi	Liuzhou	268	Shaanxi	Tongchuan	0
Liaoning	Shenyang	266	Guangdong	Yangjiang	0
Jiangsu	Zhenjiang	247	Hubei	Jingzhou	0
Jiangsu	Nantong	226	Yunan	Pu'er	0
Jiangsu	Changzhou	218	Yunan	Lincang	0

Table 5. The rank of command-and-control environmental regulation at prefecture-level in 2014.

Top 25			Last 25		
Province	City	ER	Province	City	ER
Guangxi	Hechi	3.812	Guangdong	Jieyang	0.011
Ningxia	Zhongwei	2.892	Fujian	Ningde	0.011
Gansu	Jiayuguan	2.710	Tianjin	Tianjin	0.010
Gansu	Jinchang	2.683	Guangdong	Foshan	0.010
Heilongjiang	Shuangyashan	2.300	Shandong	Yantai	0.010
Shandong	Laiwu	2.215	Hubei	Wuhan	0.009
Heilongjiang	Yichun	1.916	Sichuan	Nanchong	0.008
Gansu	Pingliang	1.827	Sichuan	Suining	0.008
Heilongjiang	Hegang	1.684	Hainan	Haikou	0.008
Ningxia	Shizuishan	1.527	Zhejiang	Wenzhou	0.008
Liaoning	Fuxin	1.445	Guangdong	Guangzhou	0.007
Shanxi	Xinzhou	1.415	Shandong	Qingdao	0.007
Shanxi	Yuncheng	1.299	Anhui	Huangshan	0.007
Gansu	Baiying	1.285	Shandong	Weihai	0.007
Yunnan	Baoshan	1.282	Fujian	Putian	0.006
Heilongjiang	Heihe	1.187	Shaanxi	Yan'an	0.005
Guanxi	Laibin	1.112	Sichuan	Chengdu	0.004
Shanxi	Changzhi	1.067	Gansu	Qingyang	0.004
Heilongjiang	Qitaihe	1.012	Sichuan	Bazhong	0.003
Heilongjiang	Jixi	0.941	Heilongjiang	Daqing	0.003
Guizhou	Liupanshui	0.900	Beijing	Beijing	0.003
Inner Mongolia	Wuhai	0.860	Hainan	Sanya	0.003
Shaanxi	Tongchuan	0.794	Sichuan	Ziyang	0.002
Liaoning	Benxi	0.740	Guangdong	Shenzhen	0.002
Shanxi	Datong	0.717	Hunan	Changsha	0.001

Heilongjiang Province, Tianjin, Qinghai Province, and other regions have lower energy prices. From Tables 4–6, we can vaguely find out the spatial relationships between technology of ECER, command-and-control environmental regulation intensity, and market-oriented environmental regulation intensity. It may be due to the delay in the performance of environmental regulations and this paper constructed the static measurement model and measurement model so as to verify.

Table 6. The category of market-oriented environmental regulation at provincial-level in 2014.

Category	Province	Price
I	Qinghai; Chongqing; Hunan; Heilongjiang; Tianjin; Hebei	1,514-1,650
II	Shanxi; Xinjiang; Liaoning; Shandong; Jilin; Sichuan	1,651-1,787
III	Shanghai; Guizhou; Hubei; Gansu; Guangxi; Beijing; Henan	1,788-1,972
IV	Ningxia; Hainan; Jiangxi; Shaanxi; Yunnan; Jiangsu; Fujian	1,973-2,142
V	Zhejiang; Anhui; Guangdong; Inner Mongolia	2,143-2,322
No data	Tibet; Taiwan; Hong Kong; Macao	-

4.2. Technical induction effects of market-oriented type and command-and-control type of environmental regulation tools

In order to avoid the false regression, the stability of panel data was firstly checked and calculated through the inter-group estimation by regression model. The results showed that $F = 5.6697$, *p-value* $<2.2*10^{-16}$, indicating that the panel data was stable. Then, we testified whether the data of the panel data possess individual and time effects. The Breusch-Pagan test results showed that *chisq* $= 1981.3$, *p-value* $<2.2*10^{-16}$, indicating that the panel data possesses individual effect and time effect at the same time.

Using R Language Software programming, mixed regression model, and GMM method to estimate the model of ECER technological innovation of environmental regulations in static and the first lag phase, the results are shown in Table 7. As far as the whole country is concerned (Models 4 and 5), the command-and-control type of environmental regulation tools did not show significantly immediate effect on ECER technology innovation but had a significantly positive impact on the technological innovation in the first lag period; market-oriented environmental regulation tools had significantly negative impact on immediate technology innovation while showed significantly positive effect in the first-lag period. As the increase of pollution emission, government control on corporate pollution emissions was stricter. Although the effect of governance is not significant in short-term, it will provoke company innovation of energy conservation technology after a year of strict control. As energy prices increase, it will increase production costs and cut investment in research and development and the introduction of talent in short term, showing negative effects on technological innovation. In order to save the cost of energy, companies began to pay attention to energy conservation technology innovation and gain positive effect in technology innovation of ECER from the second year.

In terms of the impact of the first-lag phase (Model 5), the command-and-control environmental regulation tools should be more effective in promoting technological innovation than the market-oriented environment regulation tools. It can be seen that "narrow" PH was not valid under

Table 7. The effects of command-and-control and market-oriented environmental regulations on innovation.

Variable	Eastern region immediate (Model 1)	Central region immediate (Model 2)	Western region immediate (Model 3)	National immediate (Model 4)	National fist lag phase (Model 5)
ER	−0.00022	−0.00020	−0.00029	−0.00026	
	(0.8019)	(0.8253)	(0.7449)	(0.7731)	
price	−0.02132***	−0.02242***	−0.02087**	−0.02079**	
	(0.0008)	(0.0004)	(0.001)	(0.0011)	
lag(ER, 1)					0.17310*
					(0.0702)
lag(price, 1)					0.13622**
					(0.0412)
lag(patent, 1)					0.0611*
					(0.0313)
FDI	0.09966***	0.0982***	0.10468***	0.10198***	0.07254*
	(<2.2e-16)	(<2.2e-16)	(<2.2e-16)	(<2.2e-16)	(0.0389)
R&D	0.65954***	0.65766***	0.65764***	0.65946***	0.10497**
	(<2.2e-16)	(<2.2e-16)	(<2.2e-16)	(<2.2e-16)	(0.0421)
GDP	0.10683***	0.10998***	0.11792***	0.10985***	8.41229
	(1.964e-05)	(8.621e-06)	(2.431e-06)	(9.127e-06)	(0.35080)
region	0.00264*	−0.00773**	0.00697*		
	(0.0408)	(0.0067)	(0.0284)		
constant	−0.00033	0.00413	−0.00312	−0.00027	0.18855
	(0.9285)	(0.3021)	(0.4211)	(0.9412)	(0.2366)
R2	0.47794	0.47968	0.47902	0.47776	
F test value	303.022***	305.151***	304.338***	363.536***	
Sargan					125.7746***

Brackets are standard errors; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

the background of technological innovation of China's ECER industry. It is probably due to the fact that the main body of innovation in ECER industry is state-owned companies, public universities, and research institutes. Taking the year 2014 for example, the number of patent applications of State Grid Corporation ranked the first in the quantity of patent applications of 217. Sinopec Group ranked 7th with 151 application patents. There were 28 universities among the top 50 with a total of 911 patents, which were mainly science and engineering universities, such as Zhejiang University, Beijing University of Technology, and Harbin University of Science and Technology. State-owned companies and public research institutions are important channel of policy transmission, which are important participants of China's policy of ECER. Since the beginning of 11th Five Year Plan period, the state has already taken ECER as a target for evaluating the state-owned company performance. Some high energy consuming companies such as iron and steel and petrochemical were facing tough index of ECER. In order to complete the index, the companies have actively put efforts in equipment research and process improvement planning. What's more, government has allocated considerable research funding to support the research of ECER technology research in universities. Therefore, many energy conservation research centers have been established, such as establishment of Refrigeration System and Energy Conservation Laboratory in the University of Shanghai for Science and Technology in 2010 and the Energy Conservation and Emission Reduction Research Center of Taiyuan University of Technology in 2012. Besides, economic openness and R&D per capita had a positive impact on the technological innovation of immediate period and the first-lag phase.

As Tables 4–6 shown above, there was obvious imbalance of economic and social development between different regions in China, and so were the differences in governance capacity of the local governments and effects of environmental regulations. Model 1, Model 2, and Model 3 calculated the influence of environmental regulations on immediate ECER technology innovation in the eastern, the central, and the western regions, respectively (All regional variable region coefficient introduced were noticeable, which shows obvious regional differences). The command-and-control environment regulation tools in three economic zones had no significant immediate impact on the technological innovation of ECER. The market-oriented environment regulation tools played a negative role in the immediate technology innovation and the central region showed the strongest negative effect of the market environment regulation tools followed by the eastern region and the western region shows weakest effect. The technical level and market economic vitality in the central region stayed in the middle and undertook large number of energy-intensive industries burden for the eastern region, resulting in high energy consumption of coal, oil, and electricity, etc. During the period of 2008–2014, the unit GDP energy consumption of the central region was 0.967 tons/ten thousand yuan, which was higher than the 0.704 tons/ten thousand yuan of the eastern region. The increase in energy prices posed greater influence to companies of central region than those of the eastern region and cost pressures would immediately lead to a cut in R&D spending of companies and the obstacle in technology innovation. The eastern region had a higher level of economic development and technology with stronger market economic vitality, which were supposed to be greatly influenced by market price fluctuation energy. However, the transfer of energy intensive industries burden saved them and helped the companies of the central region to stay in the middle in the fluctuation influence of the overall technological innovation by energy price increase. The western region had higher energy consumption per unit GDP, which was 11,300 yuan/ton from 2008 to 2014. Compared with the eastern region, its technical level, market economy vigor still had long distance to catch while on the whole, its fluctuation of company technology innovation by energy market price was less than the eastern region.

5. Conclusions

We established the model of ECER technological innovation of environmental regulations in static and the first-lag phase by adopting mixed regression model and systematic GMM method to examine the influence of command-and-control type and market-oriented environmental regulation tools on ECER technology innovation on the prefectural-level. The main conclusions are as follows:

(1) From characteristics of the time sequence evolution, the command environment regulation tools had no significant influence on the technological innovation of China's ECER technology immediately while they had a significant positive impact on the technical innovation of the first-lag phase. The market environment regulation tools had a significant negative influence on immediate technology innovation and the technical innovation of the first-lag phase was significantly positive. We can draw the conclusion that "weak" PH claims that environmental regulations can stimulate the established view of company innovation on certain prerequisite, which means the induced effect of environmental regulations on innovation needs to take

one year to be effective (Since this paper only collected data of seven years, the period sample is not long enough. Thus, the results of the lag phases ii and iii were lower in credibility and not included). In the short term, environmental regulations cannot promote company technology innovation and even may lead to the production cost increase of companies and thus hinder the role of technological innovation. But in the long run, both the strict command-and-control and market-oriented economic means can provoke innovation. We notice that scholars now are paying more attention to the selection of environmental regulation indicators when testified the validation of "weak" PH, which might carry ambiguous, even totally different meaning between indicators and neglect time constraints on the impact of environmental regulations on technical innovation (Jiang et al. 2014; Huang et al. 2015).

(2) In terms of the impact of environmental regulation tools on ECER technologies in China, the command-and-control environmental regulation tools are more effective in promoting technological innovation than market-oriented type. The idea advocated by the "narrow" PH of flexible market-oriented environment regulations is more effective than the command-and-control type in stimulate innovation turned out untenable. This is related to the fact that currently state companies and universities are the most important participants in China's policy of ECER technological innovation. For a long time, state-owned companies are functioning as the pioneer of China's ECER. Since the carrying out of 11th Five Year Plan, the state has already take ECER as targets in evaluating the state-owned company performance and the career of the head of the company. This kind of mechanism has ensured the effective execution of China's ECER policy. The state also allocated a large amount of research funding to support the university's research on ECER technologies. In western countries, the main participant of ECER is more diverse and energy service companies such as private energy conservation advisory bodies are also important innovation subjects.

(3) From the features of spatial differentiation, the command-and-control environmental regulation tools in the eastern, the central, and the western regions had no significant impact on the immediate ECER technological innovation. The market-oriented environment regulation tools played a negative role in the immediate technical innovation. The market environment regulation tools in the central region showed the strongest negative effect and the eastern region was the weaker while the western region was weakest. This is because energy consumption per unit of GDP in the central region was higher than the eastern region, and the cost pressure of energy price increase was disadvantageous to technological innovation. The eastern region was featured as the strongest in market economy, which was deeply affected by the fluctuation of energy price. However, its energy consumption per unit of GDP stayed lowest, which was slightly affected by the fluctuation of energy price. The combination of these two effects leads to the negative effect of the market-oriented environment regulation tools in the eastern region. Although the energy consumption per unit of GDP in the western region was higher while the market economic vitality was lower than that of the eastern region, the negative influence by energy price was relatively low.

The above empirical results lead us to the following policy implications: first, environmental regulations in China can promote regional ECER technology innovation, and command-and-control type of environmental regulation policy effect is more significant. Therefore, we should firstly improve environmental legislation and regulation, and strictly enforce the laws of ECER standards so as to meet the command index. Also, we shall accelerate the research of ECER policies, such as steadily advancing environmental tax reform and improving the trading mechanism of emission rights. Secondly, it is necessary to accelerate the popularization and application of ECER technologies and establish network of technical cooperation for regional ECER. At present, the technological innovation level of ECER in the eastern region is relatively higher while the central part is lower, so the companies in the central cities need to carry out collaborative innovation activities of environmental protection technology cooperate with companies in eastern cities such as Beijing and Shanghai. In addition, we should give full play to the main force and exemplary power of state-owned companies and universities in environmental innovation and actively guide the application of their environmental technologies. Thirdly, formulation of the environmental regulation system shall be targeted and spatially different. According to the characteristics of the market-oriented environment regulation effect in the eastern, the central, and the western regions, we shall implement flexible environmental regulation policies.

Notes

1. Eastern regions refer to Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, and Hainan, covering 11 provinces and provincial-level municipalities. The central region includes Shanxi, Inner Mongolia, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei, Hunan, covering nine provinces and autonomous regions. Western region refers to Chongqing, Guangxi, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang.
2. Tibet, Lhasa City, and Sansha City of Hainan Province have no patent of ECER; these are therefore not included in the study. Based on the availability of statistical data, Hongkong Special Administrative Region, the Macao Special Administrative Region and the Taiwan province were not included in the study.

Disclosure statement

No potential conflict of interest was reported by the authors.

References

Ambec S, Cohen MA, Elgie S, Lanoie P. 2013. The Porter hypothesis at 20: can environmental regulation enhance innovation and competitiveness? Rev Environ Econ Policy. 7(1):2–22.

Brunnermeier SB, Cohen MA. 2003. Determinants of environmental innovation in US manufacturing industries. J Environ Econ Manage. 45(2):278–293.

Chen Y, Ren JL, Chen YB, Xu CL. 2016. Spatial evolution and driving mechanism of China's environmental regulation efficiency. Geographical Res. 35(1):123–136.

Chintrakarn P. 2008. Environmental regulation and US states' technical inefficiency. Econ Lett. 100(3):363–365.

Cullen JA, Mansur ET. 2017. Inferring carbon abatement costs in electricity markets: a revealed preference approach using the Shale revolution. Am Econ Journal-Economic Policy. 9 (3):106–133.

Domazlicky BR, Weber WL. 2004. Does environmental protection lead to slower productivity growth in the chemical industry. Environ Resource Econ. 28(3):301–324.

Feng C, Shi BB, Kang R. 2017. Does environmental policy reduce company innovation?-evidence from China. Sustainability. 9(6):1–24.

Hamamoto M. 2006. Environmental regulation and the productivity of Japanese manufacturing industries. Resour Energy Econ. 28(4):299–312.

Huang ZJ, He CF, Yang F, Zhou Y. 2015. Environmental regulation, geographic location and growth of firms' productivity in China. Acta Geographica Sinica. 70(10):1581–1591.

Jaffe AB, Palmer K. 1997. Environmental regulation and innovation: a panel data study. Rev Econ Stat. 79(4):610–619.

Jiang FX, Wang ZJ, Bai JH. 2014. The dual effect of environmental regulation's impact on innovation. China Ind Econ. 31(7):44–55.

Lanoie P, Patry M, Lajeunesse R. 2008. Environmental regulation and productivity: testing the Porter hypothesis. J Productivity Anal. 30(2):121–128.

Ma HY, Oxley L, Gibson J, Kim B. 2008. China's energy economy: technical change, factor demand and inter factor/inter fuel substitution. Energy Econ. 30(5):2167–2183.

Popp D. 2003. Pollution control innovations and the clean air act of 1990. J Policy Anal Manag. 22(4):641–660.

Rexhaeuser S, Rammer C. 2014. Environmental innovations and firm profitability: unmasking the Porter hypothesis. Environ Resource Econ. 57(1):145–167.

Shen N, Liu FC. 2012. Can intensive environmental regulation promote technological innovation? Porter Hypothesis reexamined. China Soft Science. 27(4):49–59.

Testa F, Iraldo F, Frey M. 2011. The effect of environmental regulation on firms' competitive performance: the case of the building & construction sector in some EU regions. J Environ Manage. 92(9):2136–2144.

Wagner M. 2007. On the relationship between environmental management, environmental innovation and patenting: evidence from German manufacturing firms. Res Policy. 36 (10):1587–1602.

Wang BB, Qi SZ. 2016. The effect of market-oriented and command-and-control policy tools on emissions reduction innovation: an empirical analysis based on China's industrial patents data. China Ind Econ. 33 (6):91–108.

Wang GY, Wang D. 2011. Porter hypothesis, environmental regulation and companies' technological innovation. China Soft Science. 26(1):100–112.

Yu W, Chen Q. 2015. 20 years of Porter Hypothesis: a literature review on the relationship among environmental regulation, innovation and competitiveness. Sci Res Manag. 36(5):65–71.

Zhang CH, Liu HY, Bressers HTA, Buchanan KS. 2011. Productivity growth and environmental regulations-accounting for undesirable outputs: analysis of China's thirty provincial regions using the Malmquist- Luenberger index. Ecological Econ. 70 (12):2369–2379.

Notice of correction

Please note that this article was originally published on 27 December 2017 with errors to Tables 4, 5 and 6. The paper has now been corrected online and in print.