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The Effect of Environmental Regulation on Technological Advancement: Based on Empirical Analysis of Chinese Provincial Panel Data

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Abstract: This paper is an empirical study of the effect of environmental regulation upon technological advancement based on the panel data collected from 30 provinces, municipalities and autonomous regions in mainland China from 2000 to 2010. The results show that on a national basis environmental regulation has a positive effect upon technological advancement , but there lies regional disparity between the east, middle and west of China: The effect is positive in the east while negative in the middle and west. This paper further proves the effect of environmental regulation upon technological progress follows an inverted "N"-shaped curve and then puts forward some policy suggestions.

Key Words: environmental regulation, technological progress, panel analysis

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1. Introduction

Recent years, with the rapid increase of its GDP, China has developed into the second largest world economy. Yet along with its economic growth is increasing energy consumption and deteriorating environment. Local governments are faced with the dilemma between clean environment and GDP growth due to the fact that the latter, to a large extent, is achieved through extensive growth pattern featuring high energy consumption and high investment and is unsustainable in nature as it is bound to bring about the results of high emissions, environmental deterioration and resource waste. In 2013, China's energy consumption totaled to 3.79 billion tons of coal, up 3.9% over that of 2012. Under such circumstances, environmental regulation is a must choice.

Traditional views hold that environmental regulation will have a negative impact upon enterprises, resulting in more operation cost and slower economic growth, while revisionists believe environmental regulation will help promote technological advancement and sustainable development of enterprises. Many scholars have conducted empirical studies related to this and generally come to two opinions:

The first opinion is that environmental regulation stimulates technological advancement. Typical of such a positive opinion is Porter (1991). Porter concludes from his studies that proper environmental regulation measures will not only help improve social welfare, but motivate enterprises to increase research and development input and implement technological innovation so as to adopt cleaner production and develop cleaner products, upgrade production technologies or even develop new production pattern or products to meet the requirement of environmental regulation policies. Later, Porter and Linde (1995), based on their studies on the factors that influence the supply and demand of technological innovation, prove through cases that strict environmental regulations are quite likely to stimulate innovative activities of enterprises. This is the very source of the famous "Porter Hypothesis". Afterwards scholars have tried to explore into the hypothesis, delving into the mechanisms by which environmental regulation might affect technological innovation and empirical studies concerned. Lnajuow and Mody (1996), based on the data of patent inventions in USA, Japan and Germany from 1972 to 1986, studied the relationship between environmental regulation and technological invention across industries. The results show that higher waste disposal costs leads to more patent inventions. Mohr (2002) introduced external scale economy indexes to his study and assumed the new productive capital produces fewer pollutant emissions than the old one, and found that environmental regulation will help improve productivity as well as reduce pollution. Brunnermeirer and Cohen (2003) conducted an empirical study on the relationship between the number of environmental protection patents applied and environmental regulation and found that there exists a statistically significant positive correlation between the two. The empirical studies of Horbach (2008) based on the data of German enterprises and of Murty and Kumar (2003) based on panel data of Indian enterprises suggest that environmental regulation exerts a clearly positive effect upon technological progress in environmental protection

industries.

The second opinion argues that environmental regulation has little or even a negative effect upon technological advancement. Environmental regulation is purposed at rectifying “market malfunction”, internalizing negative externalities into production costs. This kind of analysis is always based on static standards, that is, to analyze the effect of environmental regulation upon enterprise costs and profits on the hypothesis that technology, resource allocation and consumption demand of enterprises are not changeable (Cropper, Gates, 1992). In the frame of such static models, environmental regulation is sure to result in rising costs of enterprises, hence a negative effect upon technological progress as rising costs mean reduced investment in technological innovation. Gray and Shadbegian (1995), based on the data of 259 American enterprises from 1979 to 1990, studied the relationship between environmental regulation measures and total factor productivity of enterprises and found that the rising costs in pollution treatment leads to lower productivity. This remains a common trend among the three industries covered in the study though the effect may function in different degree due to the enforcement of those environmental regulation measures at different standards. An earlier survey targeted at five industries that are labeled with serious pollution in USA concerning manufacturing of paper, chemical products, stone and glass, steel, and non-ferrous metal, comes to the same conclusion (Barbara and <connell, 1990). Jaffe and Palmer (1007), by using total expenses on research and development and total number of patents successfully applied as indexes for technological innovation, and pollution treatment cost as the index for environmental regulation, explored the relationship between environmental regulation and technological innovation based on the interval data of American manufacturing industry from 1975 to 1991 and found no significantly positive correlation between the number of patents and environmental regulation.

Scholars at home are concerned about this issue too. Xu Qingrui et al. (1995)conducted a study based on interviews with over 50 enterprises in Jiangsu and Zhejiang provinces and found that governmental policies and laws are the primary stimulus for enterprises to scheme technological innovation that helps improve external environment, while public opinion and other economic means such as pollution treatment charges are not so inducing. This fully demonstrates environmental regulation has a positive effect upon technological innovation. The studies of Zhang Qizi et al. (2006) concluded that the correlation between environmental protection and technological innovation policies in China needs to be improved. Huang Dechun and Liu Zhibiao (2006) conducted a case study of Hai’er Group and suggested that proper environmental regulation contributes to environmental improvement and technological innovation of enterprises. Wang Junhao and Li Yunyan (2009), through a questionaire-based survey of 78 textile enterprises in Zhejiang Province, classified enterprises into “active” and “defensive” groups in terms of strategies they adopted to cope with environmental regulation and found that compared with the latter, the former group of enterprises are more inclined toward technological innovation activities like developing green processing technology or green products. Zhao Hong (2008), based on the panel data of China’s industrial enterprises from 1996 to 2004 , analyzed the effect of environmental regulation upon research and development investment and authorized patents and pointed out that environmental regulation, to certain extent, enhances technological innovation of Chinese enterprises. The study of

Jiang Ke (2009) shows that environmental regulation stimulates technological innovation competence of enterprises, yet there lies regional disparity: the stimulating effect is significant in the east while not so much in the middle-west and northeast of China.

Besides, some scholars have studied the relationship between environmental regulation and technological progress by analyzing the effect of environmental regulation upon enterprise productivity. Zhang Cheng et al. (2011), based on China's provincial panel data from 1998 to 2007, constructed a mathematical model to analyze the relations between environmental regulation and production technology advancement. The results reveal that the relationship between environmental regulation and technological progress in China's eastern and middle areas follows a "U"-shaped curve, but that in the west is no clear yet. Li Ling and Tao Feng (2012) examined the relationship between environmental regulation and green total factor productivity based on a panel model. Their study labeled manufacturing enterprises with serious pollution, medium pollution and light pollution according to the severity of pollution they may produce and found that for enterprises labeled with serious pollution, the relationship between environmental regulation and green total factor productivity, technological progress and technological efficiency agrees with an inverted "U"-shaped curve, but for the rest two kinds of enterprises, the above-mentioned relationship follows a "U"-shaped curve.

It can be concluded that scholars both home and abroad have achieved much in studying the relationship between environmental regulation and technological progress, both theoretically and empirically. However, for one thing, most of these studies choose enterprises from developed countries as the sample. For another, there is no consensus on the conclusion; indeed, many conclusions are drawn that may vary between nations, regions and even industries. Therefore, it is of great need to further study the relationship between environmental regulation and technological advancement in China. This paper is to study the effect of environmental regulation upon technological advancement based on data covering China's 30 provinces, municipalities and autonomous regions from 2000 to 2010.

This paper intends to address the following questions: Will environmental regulation stimulate technological advancement? Considering huge differences between regions and between urban and rural areas and different paces of marketization in China's east, middle and west, will the effect show regional disparity too? This paper is structured as follows: first, it presents a literature review of previous studies to analyze how environmental regulation would work on technological progress. Then it conducts an empirical analysis both on a national and regional basis of the data collected from China's 30 provinces, municipalities and autonomous regions concerning environmental regulation and technological advancement with a view to reveal the effect of environmental regulation upon technological progress in China. Finally there comes the conclusion as well as policy suggestions. The following part of the paper includes analysis of mechanisms by which environmental regulation may enhance technological progress in Part Two, formulation of measurement model, results and explanations in Part Three, verification of effect models of environmental regulation upon technological advancement in Part Four and conclusion and policy significance in Part Five.

2. Mechanisms by Which Environmental Regulation Enhances Technological Advancement

Generally speaking, technological advancement is attributed to its inherent development, need of economic development and market demand, and incentive measures adopted by the government as well. A nation will always encourage technological innovation and advancement through supportive or regulatory measures. The supportive measures include funding public research and development institutions and granting research and development subsidies, etc., while regulatory measures mean the government establishes norms and standards through taxation and social contract, etc. to direct technological advancement of enterprises. Enterprises respond to governmental regulations and benefit from gradual innovation in product and production process and the spreading of such technologies. Environmental regulation may enhance technological innovation through the following mechanisms.

2.1 Signal mechanism of reducing investment uncertainty

Environmental regulation enables enterprises to recognize the negative effect of resource utilization upon environment and "forces" them to realize the prospect of economic gains that can be obtained from environmental improvement. Meanwhile it frames technological advancement scheme for enterprises so that they need not worry about the possible risks of technological innovation. Environmental regulation policies are always featured by rigidity, predictability and flexibility. Related studies prove that all these three features have a significantly positive effect upon technological innovation, in particular the feature of unpredictability. Unpredictability is more effective than rigidity in that the latter is only part of environmental policies while the former can induce investment activities of enterprises (including risk investment) (Johnstone et al, 2010).

Where environmental regulation policies are actively implemented, both enterprises and consumers will have enhanced awareness of developing or consuming green products. As a result, there will be notably more "green" products sold in the market. Green or organic food counters appear in the supermarket, and the advertising brochures emphasize that consumption of such products produce no harm to environment as well as human body. As environmental regulation becomes increasingly strict, enterprises extend the concept of developing green products from environment-friendly qualities of the end product to green production, green disposal and the like, yearning for developing products which are cost-saving in production, environment-friendly in use, and easy to be disposed of and ready for recycling after use.

2.2 Prohibitive regulation and cost pressure mechanism

Under environmental regulation, environmental cost is included in the production process of enterprises. That means production cost rises and hence "cost pressure" is generated. In order to reduce cost, enterprises would have to go in for technological innovation. Environment taxation would guide enterprises toward resource reallocation. For example, enterprises would be encouraged to reduce energy consumption and emission if higher taxes are levied on industries that are traditionally acknowledged for heavy pollution and high emission, and the ratio of taxes in energy pricing system is

adjusted. Besides, enterprises would be encouraged to invest more money in environmental protection projects if more favorable taxation rules regarding utilization of renewable energies and tax return matching policies are introduced to integrate taxation with utilization, and punishment with encouragement.

Upon the enforcement of a prohibitive regulation, enterprises would have two choices: either to upgrade technologies or withdraw from the market. What most enterprises would probably choose is technological innovation in conformity with the regulation. For example, lead will do great harm to joints and liver if kept long in human body. In 1974 the American government issued *Clean Air Act*, requiring related enterprises to reduce lead content in petrol and provide consumers with non-lead petrol to choose. This law has been a great impetus to the upgrading of catalyst material used for car ignition [3].

2.3 Mechanism of environmental regulation enhancing industrial structure optimization

Under environmental regulation, those enterprises featuring heavy pollution and poor competitiveness and not being able to meet certain environmental standards would be excluded, while new enterprises would have difficulty in entering because of high environmental standards. This helps retain those large and highly competitive enterprises that are moderately numbered and with stable business in the industries and markets concerned. This also helps maintain within certain industries a relatively high level of market concentration which facilitates scale production and technological innovation targeted at better competitiveness. In other words, environmental regulation would enhance industrial concentration and hence industrial upgrading. Under environmental regulation, modern industrial system would have a greener structure, which is characterized by closing down outdated production facilities, attaching importance to energy saving and emission reduction of traditional industries and upgrading the whole industrial chain. Synder et al. (2003) proved that America's environmental regulation policies concerning chlorine production have resulted in a dramatic change in chlorine users' need of the product and hence closing down of those enterprises failing to renew production technologies. Environmental regulation has helped enterprises using new chlorine production technologies win more market share and promote the application of technologies of high efficiency.

2.4 Subsidy-based incentive mechanism

Due to the fact that technology is a kind of public product, research and development activities of production knowledge and technologies will inevitably be confronted with such problems as market malfunction and investment deficiency. Accordingly, developing countries would solve such external problems by means of taxation exemption, research subsidies and public polices, etc. It is said in the Report of the Eighteenth Congress of CPC that, in the face of tighter resource constraints, worsening environmental pollution and degrading ecosystem, ecological civilization construction must be highlighted to be an integral part of economic, political, cultural and social construction. It is also said in the report that it is necessary to deepen reforms on resource-based product pricing and taxation systems,

[3] Qiu Zhaoyi, *On the Effect of International Vertical Specialization upon China's Environment*, Economic Science Press, 2013.

establish resource paid-use and ecological compensation policies that reflect market supply and demand and scarcity degree of resources as well as ecological value and inter-generation compensation. This requires the government to use such means of favorable taxation policies and subsidies to encourage enterprise to go in for technology renewing. The government subsidies contribute to the enhancement of research and development and self-dependent innovation of enterprises. The government's incentive mechanism of granting subsidies for research and development activities will help motivate enterprises to invest more in such activities and be self-dependent in technological innovation.

3. Empirical Models and Test

3.1 The Choice and Formulation of Empirical Models

Related economic theories tell that technological progress is an economic phenomenon or, indeed, an output. Its production process is the one that produces new knowledge based on labor, capital and regulations. The production function of technological innovation can be expressed as follows:

$$tech = Af(k, l, z) \qquad (1)$$

In Formula (1), A stands for institutional factors; tech for technological advancement-based output in the course of technological innovation; L for labor input in the course of technological innovation which in this paper mainly refers to input of technical personnel (human); k for capital input in the course of technological innovation which in this paper involves two aspects, foreign direct investment (fdi) and research and development input (rnd); and z for other factors that may affect technological innovation in the course which, in this paper, mainly include environmental regulation level (envir) and degree of economic opening across China (trade) and technology spillover due to opening up, typically in the form of foreign trade. Accordingly, this paper constructs a more general production function as shown below:

$$tech = Af(fdi, rnd, envir, human, trade, market) \qquad (2)$$

Based on Formula (2), this paper establishes a test model similar to that of Amiti & Wei (2004) to analyze factors that influence technological advancement:

$$tech_{i,t} = c + \alpha_1 envir_{i,t} + \alpha_2 rnd_{i,t} + \alpha_3 fdi_{i,t} + \alpha_4 human_{i,t} + \alpha_5 trade_{i,t} + \alpha_6 market_{i,t} + \varepsilon_{i,t} \qquad (3)$$

tech here refers to technological advancement index of each province; the variable subscript i to different province (municipality); subscript t to year; and a and c to parameters to be estimated.

3.2 Variable Explanation and data source

Variable Explanation

Technological advancement (*TECH*). The course of technological advancement is the very same process in which enterprises develop proprietary core technologies and realize value increment of the new products. It is a complicated question how to measure technological advancement. A variety of methods have been mentioned in related literature. Quite a few studies chose patent output as a proxy

variable for technological progress (涂红星，肖序 2014). Considering that in reality many technological advancements are micro-innovations which may not be converted to patents, some other studies used total factor productivity as the proxy variable of technological advancement (黄凌云 吴维琼，2013). Denoting "production efficiency within certain period of time", total factor productivity is virtually an indirect index that requires calculation. In view of the easy accessibility of provincial data, we chose the index of energy consumption per GDP in China's provinces, municipalities and autonomous regions to evaluate technological advancement. This seems to be more reasonable than using patent number to evaluate technological advancement for technological progress does not necessarily correspond to patent acquisition in real life. Sometimes it may only be a tiny advance in production process, but this can also be reflected in energy consumption per GDP. Therefore, this paper chooses energy consumption per GDP to indicate technological advancement .

Environmental regulation level (*ENVIR*). Due to the large variety of environmental regulation tools and the data concerning intensity of each tool are not so accessible and of low quality, previous scholars, based on different research objectives, have measured environmental regulation from the following perspectives: environmental regulation policies, ratio between pollution treatment input and the total

Table 1: Effect of Environmental Regulation on Technological Advancement

Variable	Variable Name	Variable Explanation	Data Source
Tech	technological advancement	Measured by energy consumption per GDP, expressed as *ln(1+tech)* in the model	China Energy Statistical Yearbook, China Statistical Yearbook
Envir	environmental regulation	Measured by the ratio between the amount of industrial wastewater discharged in the area and the total amount of industrial wastewater discharged, expressed as *ln(1+env)* in the model	China Environment Statistical Yearbook, Local statistical yearbooks
FDI	foreign direct investment	Measured by the ratio between foreign direct investment and GDP of the area, expressed as *ln(1+fdi)* in the model	China Statistical Yearbook and local statistical yearbooks
R&D	research and development input	Measured by the ratio between research and development expenses and GDP of the area, expressed as *ln(1+rnd)* in the model	China Science and Technology Statistical Yearbook and local statistical yearbooks
Human	Human capital	Measured by the proportion of population with junior college education and above, expressed as *ln(1+human)* in the model	China Statistical Yearbook and local statistical yearbooks
Trade	International trade	Measured by the ratio between foreign trade volume and GDP of the area, expressed as *ln(1+trade)* in the model	China Statistical Yearbook and local statistical yearbooks
Market	market mechanism	Measured by the ratio of private economy, expressed as *ln(1+market)* in the model	China Statistical Yearbook and local statistical yearbooks

input or production value of enterprises, costs for operating pollution treatment facilities, per capita income, frequency of environmental regulation institutions inspecting and monitoring pollution treatment of enterprises, changes in pollutant emission amount under environmental regulation (张成等 2014). This paper measures environmental regulation level by the index of industrial wastewater discharge standards, that is, the ratio between the amount of industrial wastewater discharged in the area and the total amount of industrial wastewater discharged.

Control variables. The ratio of research and development expenses (*R&D*): measured by the ratio between research and development expenses and GDP of that area; Trade openness (*TRADE*): measured by the ratio between import and export trade volume and GDP of that area. Human capital (*Human*): measured by the proportion of population with junior college education and above. Marketization degree (*MARKET*): measured by the ratio of private economy.

A natural logarithm has been chosen for all the above-mentioned variables when estimation is made. Accordingly, estimated coefficient ahead of the variable can also be deemed as an elastic coefficient. Please see Table 1 for details of these variables.

In empirical analysis, we group provinces, municipalities and autonomous regions in mainland China into east, middle and west areas, among which the east areas include the 12 provinces (municipalities and autonomous regions) of Liaoning, Beijing, Hebei, Tianjin, shandong, Jiangsu, Shanghai, Fujian, Zhejiang, Guangdong, Guongxi and Hainan; the middle areas include the 10 provinces (municipalities and autonomous regions) of Inner Mongolia, Shanxi, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei, Hunan; and the west areas include the 10 provinces (municipalities and autonomous regions) of Sichuan, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang and Chongqing. Due to unavailable data, Tibet is excluded in this paper. That means this study covers 30 provinces, municipalities and autonomous regions. And the time span was from 2000 to 2010.

3.3 Analysis of test results

Based on the theoretical analysis of the mechanisms through which environmental regulation influences technological advancement, we make a regression analysis by introducing energy consumption per GDP as the explanatory variable. Due to the fact that this study mainly analyzes the effect of environmental regulation upon technological progress in 30 provinces of mainland China, we choose the panel data model featuring fixed effect for analysis. The empirical analysis is conducted on the basis of national panel data and provincial panel data respectively.

Table 2 shows the results of empirical analysis based on national panel data. When making the analysis by gradually adding to it other control variables, we find that the effect of environmental regulation upon technological progress is statistically positive. This finding means: for one thing, environmental regulation does have a positive effect on technological innovation of China as a whole; for another, the regression result is relatively stable. Take Model 4 as an example. The influence coefficient of environmental regulation upon technological advancement is estimated to be 0.601, suggesting that whenever environmental regulation level is up 1%, technological progress will rise 0.601%. It can be concluded that taking the country as a whole, environmental regulation, to certain

degree, leads to technological improvement of China.

Our analyses of control variables indicate that more R&D input will help enhance technological advancement; the regression coefficient of human capital suggests that, to certain extent, it can promote technological advancement; foreign trade and FDI have a positive effect upon technological improvement, showing that its opening-up has contributed to technological advancement of China. This does not agree with the conclusion of Zhang Zhongyuan and Zhao Guoqing (2012) which suggests spillover effect of FDI hindered technological progress.

In Model 4, we also examined the combined effect of environmental regulation and marketization degree and found that environmental regulation would help with technological advancement through market mechanism.

Table 2: The Effect of Environmental Regulation upon Technological Advancement: An Analysis on a National Basis (2000-2010)

	Model 1	**Model 2**	**Model 3**	**Model 4**
C	3.104*** (0.421)	2.144** (0.633)	4.015* (1.116)	5.157 (1.306)
Envir	0.635** (0.498)	0.633* (0.393)	0.719*** (0.322)	0.601** (0.361)
FDI		0.539** (0.472)	0.692*** (0.394)	0.553** (0.495)
R&D		0.491** (0.409)	0.347*** (0.384)	0.262** (0.493)
Human		0.021** (0.501)	0.039*** (0.264)	0.028** (0.381)
Trade			0.056** (0.374)	0.092** (0.518)
Market			0.066* (0.416)	0.023* (0.337)
*Envir *Market*				0.093* (0.347)
AR2	0.513	0.487	0.662	0.649
F	145.61***	120.51***	109.38***	141.47***
DW stat	1.387	1.401	1.657	1.588
obs	330	330	330	330

Note: Statistical software is Eviews60. . *, **, *** respectively mean being significant below the significance level of 10% , 5% and 1%; in the brackets is the standard deviation value (The same with Table 3).

Viewing the huge disparity between the east and west of China in terms of economic development, environmental management and marketization, the effect of environmental regulation upon technological advancement may vary from area to area. What follows is the regression analysis of the east, middle and west areas to analyze the possible differences among different regions.

Table 3 is the regression analysis of the classified areas based on panel data. Estimated results prove that there exists regional disparity when it comes to the effect of environmental regulation upon

technological advancement. To detail it, environmental regulation in the east has lead to its technological improvement, while environmental regulation in the middle and west of China has restricted their technological advancement. One possible reason may be due to the differences between the east and the middle and west in terms of economic structure and development. Another possible reason is that in those economically developed areas, market mechanism works better so that environmental regulation will function better to guide technology advancement, hence a more conspicuous effect.

Table 3: The Effect of Environmental Regulation upon Technological Advancement: an Analysis on a Regional Basis (2000-2010)

	East		Middle		West	
	Model 5	**Model 6**	**Model 7**	**Model 8**	**Model 9**	**Model 10**
C	8.185*** (0.448)	6.547** (0.569)	4.254* (1.099)	7.137 (1.876)	5.214*** (0.461)	6.223** (0.572)
Envir	0.813** (0.373)	0.753* (0.462)	-0.013*** (0.117)	-0.017*** (0.3284)	-0.015*** (0.282)	-0.012* (0.421)
FDI	0.604** (0.422)	0.553** (0.499)	0.366* (0.228)	0.573** (0.316)	0.497*** (0.321)	0.356** (0.473)
R&D	0.403** (0.486)	0.372** (0.399)	0.326*** (0.226)	0.312** (0.372)	0.288*** (0.298)	0.215** (0.449)
Human	0.015** (0.477)	0.027** (0.468)	0.039*** (0.321)	0.019** (0.236)	0.009*** (0.471)	0.008** (0.377)
Trade	0.023* (0.478)	0.027** (0.419)	0.025*** (0.291)	0.018** (0.448)	0.006*** (0.442)	0.002** (0.477)
Market	0.003* (0.428)	0.005* (0.463)	0.001* (0.301)	0.007** (0.411)	0.006*** (0.432)	0.003** (0.499)
*Envir *Market*		0.502* (0.169)		-0.014* (0.333)		-0.009* (0.465)
AR2	0.595	0.628	0.672	0.791	0.683	0.816
F	74.27***	88.31***	102.52***	117.77***	89.47***	93.57***
DW stat	1.632	1.257	1.331	1.502	1.419	1.602
obs	132	132	99	99	99	99

4. Type Test of the Effect of Environmental Regulation upon Technological Advancement

In our study we intend to analyze some kind of non-linear relationship between environmental regulation and technological advancement. This is similar to the study of Tu Hongxing and Xiao Xu (2014) which demonstrated that the relationship between environmental regulation and self-dependent innovation follows a "U'-shaped curve, resembling the Environmental Kuznets Curve. In order to test whether there is a similar relationship between environmental regulation and technological improvement, and how the former works on the latter, we constructed the following model.

$$tech_{i,t} = \alpha + \beta_1 envir_{i,t} + \beta_2 envir_{i,t}^2 + \beta_3 envir_{i,t}^3 + \varepsilon_{i,t} \qquad (2)$$

Formula (2) is used to test the type of the effect of environmental regulation upon technological

advancement. If the estimated result is $\beta_1>0$, $\beta_2<0$ 且 $\beta_3>0$, it means the curve is a N-shaped one; or if $\beta_1<0$, $\beta_2>0$ 且 $\beta_3<0$, then the curve is an inverted N-shaped one.

Table 4: The Type of the Effect of Environmental Regulation upon Technological Advancement

	Model 11	
	Fixed Effect	Random Effect
C	2.017* (1.322)	1.96 (1.285)
envir	-0.57* (0.704)	-0.42** (0.671)
$envir^2$	1.22* (0.699)	1.35** (0. 409)
$envir^3$	-0.74* (0.572)	-0.81** (0.391)
AR^2	0.67	0.71
F	144.72***	102.51*
DW stat	1.547	1.375
Hausman test value (P value)	14.532 (0.1377)	
Observations	330	330

In Table 4 are listed the regression analysis results based on the panel data concerning the effect of environmental regulation on technological advancement. Both fixed effect and random effect results are given. The empirical analysis results suggest that Hausman test denies random effect model and favors fixed effect model. Therefore, we adopted fixed effect model to explain empirical results.

The estimated result based on Model 11 as shown in Table 4 suggests that β1<0, β2>0 andβ3<0, and it passes the statistic significance test. This means the estimated result attests to the inverted N-shaped curve hypothesis. Then it can be concluded that the effect of environmental regulation on technological advancement accords with the inverted N-shaped curve hypothesis; that is, with the enhancement of environmental regulation, its positive effect upon technological advancement will increase first and decrease later. Based on analyses mentioned above, this means taking China as a whole, its environmental regulation efforts have promoted its technological advancement, yet there lies regional disparity when it comes to the effect of environmental regulation upon technological advancement on different parts of the country: the effect is positive in the east while negative in the middle and west of China.

It can be approximated that the effect model of China's environmental regulation upon its technological advancement stays at Part II in the inverted N-shaped curve. That is to say, excluding other factors, China's technological advancement would continue favorably as environmental regulation is enhanced, yet when reaching certain point, the latter will restrict the process of the former.

5. Conclusion and Policy Suggestions

We conducted an empirical test on the effect of environmental regulation on technological advancement in inland China based on the panel data of China's 30 provinces, municipalities and autonomous regions from 2000 to 2010.

Results show that environmental regulation tends to have a positive effect upon technological improvement; in the short term, the effect functions at an accelerating speed, while in the long run, the effect will change from a positive into a negative one. Analyses on a regional basis tell that there exists regional disparity when it comes to the effect of environmental regulation upon technological advancement, which can be detailed as: environmental regulation contributes to technological progress in the east of China but incumbers the latter in the middle and west of China.

The effect of environmental regulation upon technological advancement follows an inverted "N"-shaped curve and China, as a whole, is now at Part II of the curve. On a regional basis, the east of China reaches Part II, while the middle and west are still in the declining channel of Part I. Thus, from the perspective of technological improvement, it is necessary to recognize regional differences concerning the effect of environmental regulation upon technological advancement when environmental regulation policies are implemented across China. Environmental regulation has become an important factor to learn about China's GDP growth and technological advancement.

The policy significance of this study lies in:

Environmental regulation is a "double-edge sword", which can stimulate technological advancement on the one hand and hamper it on the other. In the long term, a win-win development of China's economy and environmental civilization can only be made possible when we balance economic development and environmental protection. Of course, a good environmental regulation measure might be regarded as the best if it can both help with environmental improvement and with technological upgrading and development of enterprises.

Environment is a public good and government, enterprises and citizens all need a clean environment. Environmental pollution is a "harmful" public good which features strong negative externality and may result in market malfunction, thus requiring governmental regulation. Faced with the deteriorating environment, the government should adopt necessary environmental regulation measures. For example, due to environmental regulation, the energy consumption per 10,000 yuan GDP in 2013 totaled 0.737 tons of coal, down 3.7% over that of 2012. This is the outcome of harmonious interaction between environmental regulation and economic development and meantime that of technological progress.

Environmental regulation should ideally have the features of: 1) severity so as to reduce to the fullest extent pollutant discharge; 2) stability so as to provide enterprises scheming technological innovation with necessary planning time for their risk investment; 3) flexibility which enables enterprises to identify the effective innovation plan; 4)clarity so as to avert possible vain efforts; and 5) continuity, that is, the policy could help with the on-going innovation of environmental technology (Johnson et al. 2010).

References：

Barbara A J, Mconnell V D. The Impact of Environmental Regulations on Industry Productivity; Direct and Indirect Effects [J]. Journal of Environmental Economics and Management, 1990,(18): 50-65.

Brunnermeier S.B.,Cohen M.A.Determinants of Environmental Innovation in US Manufacturing Industries[J]. Journal of Environmental Economics and Management,2003, 45(2) : 278-293.

Cropper M L, Gates W E. Environmental economics; A Survey [J]. Journal of Economic Literature, 1992, (30): 675-740.

Horbach J. Determinants of Environmental Innovation New Evidence from German Panel Data sources [J]. Research Policy, 2008, (37): 163-173.

Gray W. B. & R. J. Shadbegian. Pollution Abatement Costs, Regulation, and Plant-Level Productivity, NBER Working Paper 4994, 1995.

Mohr RD. Technical Change, External Economies, and the Porter Hypothesis [J]. Journal of Environmental Economics and Management, 2002, 43: 158-168.

Murty MN, Kumar S. Win-win Opportunities and Environmental Regulation: Testing of Porter Hypothesis for India Manufacturing Industries [J]. Journal of Environmental Management, 2003, (67): 139-144.

Porter, M. E. American green strategy [J] . Scientific American, 1991 (4) : 168-170.

Porter M. E., Van Der Linde C. Towards a New Conception of the Environment Competitiveness Relationship [J]. Journal of Economics Perspectives, 1995, 9 (4) : 97-118.

Lanjouw, J. O., Mody, A., 1996, “Innovation and the International Diffusion of Environmentally Responsive Technology”, Research Policy, 25, 549—571.

Jaffe, A., Palmer, K. Environmental regulation and innovation: a panel data study [J]. Review of Economics and Statistics, 1997, 79 (4) : 610-619.

Johnstone N., Hascic I., Popp D. Renewable Energy Policies and Technological Innovation: Evidence Based on Patent Counts [J].Environmental and Resource Economics, 2010, 45 (1) : 133-155.

许庆瑞，王伟强，吕燕．中国企业环境技术创新研究[J]．中国软科学，1995，(5):16-20.

张其仔，郭朝天，孙天法．中国工业污染防治的制度性缺陷及其纠正[J]．中国工业经济，2006，(8):29-35.

王俊豪，李云雁．民营企业应对环境管制的战略导向与创新行为[J]．中国工业经济，2009，(9):16-26.

李玲，陶锋．中国制造业最优环境规制强度的选择:基于绿色全要素生产率视角[J]．中国工业经济，2012，(5):70-82.

江珂.环境规制对中国技术创新能力影响及区域差异分析:基于中国 1995-2007 省际面板数据分析[J]．中国科技论坛，2009，(10):28-33.

涂红星，肖序．环境管制对自主创新影响的实证研究:基于负二项分布模型[J]．管理评论，2014，(1):57-65.

黄凌云，吴维琼.FDI 技术外溢与技术差距的门槛效应:基于中国工业企业的实证研究,财经科学，2013，(3):52-59.

张中元，赵国庆．FDI，环境规制与技术进步:基于中国省级面板数据的实证分析，数量经济技术

经济研究，2012，(4):19-32.
黄德春，刘志彪．环境规制与企业自主创新:基于波特假设的企业竞争优势构建[J]．中国工业经济，2006，(3):100-106.
赵红．环境规制对产业技术创新的影响:基于中国面板数据的实证分析[J]．产业经济研究，2008，(3):35-40.
江珂，卢现祥．环境规制与技术创新:基于中国 1997-2007 年省级面板数据分析 [J]．科研管理，2011，(7):60-66.
张成，陆旸，郭路，于同申．环境规制强度与生产技术进步 [J]．经济研究，2011，(2):113-124.