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Original Research

Effect of the Intensity of Environmental Regulation on Production Technology Progress in 17 Industries: Evidence from China

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Abstract

We demonstrate the relationship between the intensity of environmental regulation and the progress of production technology. Using data from 17 industries in China during 2000-11, we estimate a dynamic model of production technology progress. Our empirical results indicate that a simple "U"-shaped relationship between the intensity of environmental regulation and industrial production technology progress does not exist. Some industries show a significant "U"-shaped relationship while others exhibit an inverted "U"-shaped relationship. Still others showed no significant relationship between production technology progress and the intensity of environmental regulation. We also found that there is no relationship between the effect of environmental regulation on industrial production technology and an industry's type of pollution.

Keywords: intensity of environmental regulation, production technological progress, "U"-shaped relationship, dynamic panel data model

Introduction

Smog is becoming an increasing problem for Chinese cities. In September 2013 the State Council of China issued an action plan for prevention and control of atmospheric pollution, showing that China has begun to strengthen environmental regulation. However, the impact of such regulations on China's incomplete industrialization remains controversial. Local governments worry that strengthening environmental regulations will cause factories to relocate, productivity and international competitiveness to decrease, and economic growth to slow. We believe that the key to the problem is understanding the effect of the intensity of environmental regulation on production technology progress. At present there is no scholarly consensus on the effect of the environmental regulation on production technology progress and economic growth. Simultaneous achievement of the goals of environmental improvement, technological progress, and economic growth exists only as an ideal. Hence, better understanding of the impact of the intensity of environmental regulation on production technology progress is critical.

At present, scholars generally hold that strict environmental regulation promotes the progress of green technology [1-3]. However, the effects of environmental regulation on production technological remain under dispute. Some scholars argue that strengthening environmental regulation benefits production technology progress. For example, Porter contended that reasonable environmental regulation can stimulate firms to improve their technology [4]. Lanjouw and Mody show that strengthening environmental regulation can promote technology innovation [5]. Huang and Liu introduce the new techniques coefficient in the Robert model, demonstrating that in addition to the increased costs that environ-

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mental regulations bring to firms, they can stimulate some innovation. Improved production technology will counterbalance all or part of the cost increases [6]. Zhao argued that environmental regulations promote enterprise technology innovation in China over the medium to long term [7]. Bai and Song analyzed the relationship between environmental regulation extent and the technical efficiency of the thermal power industry of China using regulatory levels of weak regulation, strong regulation and, non regulation, finding that environmental regulation has a positive effect on stimulating technological innovation [8]. Li indicated that environmental regulations have a positive influence on core technology innovation, showing that for every 1% increase in environmental regulation intensity, the number of invention patents and patents for the utility model will increase 0.17% and 0.07%, respectively [9]. Huang showed that environmental regulation and enterprise technology innovation interact with and influence each other [10]. Wang confirmed that the "Potter hypothesis" has strong support in the more developed eastern region of China [11]. Zhang examined the impact of the intensity of environmental regulation on industrial technological progress, finding that strengthening environmental regulation is conducive to regional industrial technological progress [12]. Sheng contended that the effect of environmental regulation on technological innovation was driven by existing regional differences, which in turn were primarily affected by the intensity of environmental regulation and the level of economic development level [13]. Yang showed that the strengthening of environmental regulation will lead to an increase in research and development and technological progress [14]. Acemoglu studied the influence of environmental regulation on directed technical change, concluding that dynamic environmental regulations can promote technical progress [15].

However, some studies find that technological progress will fall with reduced pollutant emissions [16]. Greenstone argued that environmental regulation led to a reduction in total manufacturing productivity and a decrease of technological innovation in America [17]. Other studies indicate that environmental regulation had no significant effect on the progress of production technology. Jaffe and Palmer argued that there was no distinct relationship between the number of patents and environmental regulation policy [18]. Jiang contended that environmental regulation has no significant positive effect on technology innovation in China [19]. Zhang found the relationship between the intensity of environmental regulation and that enterprise technological progress was U-shaped [20].

Though researchers have explored the effect of environmental regulation on production technology progress, few studies have researched the effect of environmental regulation effect on production technology progress across different industries and different types of pollution. Therefore, this article has two major purposes. First, we analyze the different technological choices of manufacturers in the face of different intensities of environmental regulation. We seek to explain the reasons for the existence of varying relationships between the intensity of environmental regulation and production technology progress. Second, most existing studies explored only one industry. Since different industries make different technology choices when the intensity of environmental regulation is changed, they reach different conclusions. Therefore, we use the dynamic panel-data GMM estimation method to investigate data from 17 industries.

Theoretical Framework

In this section, we briefly analyze the relationship between changes in the intensity of environmental regulation and production technology progress. When manufacturers face strengthened environmental regulation, they generally use two approaches to reduce pollution emissions. First, manufacturers can govern pollution emissions via expenditure on pollution controls. We term this effect the "government pollution technology progress effect" and regard it as green technology progress. Second, the manufacturer can use production technology innovation to reduce pollution emissions. We treat this as production technology progress. Thus, in our framework, the manufacturer chooses between green technology progress and/or production technology progress when reducing pollution.

Our model is based on Zhang [20]. We use a mathematical derivation to describe the relationship between the transformation of environmental regulation and production technology progress. We assume that pollution is produced in the process of production, and that under a given technology, the greater the manufacturer's output, the greater the pollution discharged. We assume that the production technology of the manufacturer is Hicks-neutral technology, defined as $F=A(K_A)f(K_P)$. The manufacturer's goal is profit maximization, defined as: $P{\cdot}A(K_A)f(K_P)$, where P is the output price, $A(K_A)$ is the production technology level, $f(K_P)$ is the output level at a given production technology level, and its size is related to the capital investment (K_P) of the manufacturer in production technology. We further assume that the manufacturer's product market and factor market is perfectly competitive. $W(F, E)$ represents the pollution emissions that are the function of production level (F) and pollution control expenditures (E) produced by manufacturers in the production process. Pollution control expenditures (E) consist of two parts, $E=E_A+E_E$, where E_A is the input of production technology for reducing pollution emission and E_E is the input from green technology. Following Selden and Lu, pollution is $W'(F,\cdot)>0$, $W'(\cdot, E)<0$ [21, 22]. We assume that the manufacturer's technological progress function is separate and additive. Thus, $T(T_A,T_E)=T_A+T_E$, where $T(T_A,T_E)$ is the total technology level, T_A is the level of production technology, and T_E is the level of green technology. The size of T_A and T_E is related to input and assumes $T_A'(E_A)>0$, $T_E'(E_E)>0$. We also assume that the manufacturer uses inputs used to reduce pollution emissions is: $E=\alpha A(K_A){\cdot}f(K_p)$, where $0<\alpha<1$, α is the proportion of total output used to reduce pollution, which reflects the degree of environmental regulation. The optimization behavior can be expressed as:

$$Max\Pi = \overline{P}\left[T_A(K_A)f(K_p) - aT_A(K_A)f(K_p)\right] \quad (1)$$

$$s.t. \quad W\left[T_A(K_A)f(K_p), aT_A(K_A)f(K_p)\right] = R \quad (2)$$

At this point, the manufacturer's optimal conditions are:

$$\left[P(1-a)T'_A(K_A)f(K_p)\right] + \lambda\frac{\partial W[T_A(K_A)f(K_p), aT_A(K_A)f(K_p)]}{\partial K_A} = 0 \quad (3)$$

$$\left[P(1-a)T_A(K_A)f'(K_p)\right] + \lambda\frac{\partial W[T_A(K_A)f(K_p), aT_A(K_A)f(K_p)]}{\partial K_p} = 0 \quad (4)$$

$$-PT_A(K_A)f(K_p) + \lambda\frac{\partial W[T_A(K_A)f(K_p), aT_A(K_A)f(K_p)]}{\partial a} = 0 \quad (5)$$

$$R = W[T_A(K_A)f(K_p), aT_A(K_A)f(K_p)] \quad (6)$$

From Eq. (5), we can obtain: $P=\lambda\cdot\partial W/\partial E$. By substituting it into Eq. (3), we obtain:

$$\partial W / \partial E = -\partial W / \partial F \quad (7)$$

This suggests that if a firm faces a certain level of environmental regulation, the optimal choice is to make the marginal pollution increase equal to the marginal pollution reduction in the production process.

The total technology level (T) is related with previous technology foundation and R&D expenditures (R), therefore, we assume that the total technology level (T) is the function of the level of production technology (T_A) and R&D expenditures (R). We also assume that the pollution control expenditures (E) is: $E=b\cdot R$, where $0<b<1$, b is the proportion of R&D expenditures used to reduce pollution. According to $E=aF=aT_A(K_A)f(K_p)$ and $W(F, E)=[T_A(K_A)f(K_p), aT_A(K_A)f(K_p)]$, we can obtain:

$$\frac{\partial T}{\partial T_A} = \frac{\partial T}{\partial W}\bullet\frac{\partial W}{\partial T_A} + \frac{\partial T}{\partial W}\bullet\frac{\partial W}{\partial R}\bullet\frac{\partial R}{\partial T_A} = \frac{\partial T}{\partial W}\bullet\frac{\partial W}{\partial T_A} + \frac{\partial T}{\partial W}\bullet\frac{\partial W}{\partial E}\bullet\frac{\partial E}{\partial T_A} = \frac{\partial T}{\partial W}\bullet\frac{\partial W}{\partial T_A} + \frac{\partial T}{\partial W}\bullet\frac{\partial W}{\partial E}\bullet af(K_p) \quad (8)$$

By $\frac{\partial W}{\partial T_A} = \frac{\partial W}{\partial F}\bullet f(K_p) + \frac{\partial W}{\partial E}\bullet af(K_p)$, Eq. (7), and the manufacturer's technical function, we obtain:

$$\frac{\partial T}{\partial T_A} = (\frac{\partial T_A}{\partial W} + \frac{\partial T_E}{\partial W})\bullet\left[\frac{\partial W}{\partial F}(1-2a)\right]\bullet f(K_p) \quad (9)$$

By Eq. (3) $\partial W / \partial K_A = \partial W / \partial F\bullet T_A^{'}\bullet f(K_p) + + \partial W / \partial E\bullet a\bullet T_A^{'}\bullet f(K_p)$, $\partial W/\partial F > 0$, $0 < a < 1$

Using $\partial W/\partial E = -\partial W/\partial F$, we can obtain $\partial W/\partial K_A > 0$. Further, since $P(1-a)T_A\cdot f(K_p)>0$, we obtain: $\lambda<0$. Substituting $\lambda<0$ into (5), we then obtain: $\partial W/\partial a<0$. This shows that as the proportion of inputs of pollution control technology in the total profits of manufacturer increase, pollution emissions decline. According to Eq. (9), as environmental regulation tightens, manufacturers must reduce pollution emissions. $\partial W/\partial a < 0$ shows that when the intensity of environmental regulation increases, α increases and pollution emissions decrease. When $\alpha\in[0, 0.5]$, manufacturers have less pressure to reduce emissions. For $\left[\frac{\partial W}{\partial F}(1-2a)\right]\bullet f(K_p) > 0$, when $T'(T_A, \cdot)>0$, we obtain $\frac{\partial T_A}{\partial W} + \frac{\partial T_E}{\partial W} > 0$. At this time, if manufacturers choose green technology, $E=E_E$, for $\partial W/\partial E<0$, $\partial T_E/\partial E>0$, then $\frac{\partial T_E}{\partial W} < 0$. We thus obtain $\frac{\partial T_A}{\partial W} > 0$, and $\frac{\partial T_A}{\partial a} = \frac{\partial T_A}{\partial W}\cdot\frac{\partial W}{\partial a} < 0$. This shows that when the intensity of environmental regulation is lower, as it rises, pollution emissions by manufacturers fall. Thus, the level of production technology of the manufacturers declines. If manufacturers choose production technology, then $E=E_A$, $\frac{\partial T_A}{\partial W} = \frac{\partial T_A}{\partial E_A}\bullet\frac{\partial E_A}{\partial W} < 0$ (as a result of $\partial W/\partial E<0$, $\partial T_A/\partial E_A>0$), and $\frac{\partial T_A}{\partial a} = \frac{\partial T_A}{\partial W}\cdot\frac{\partial W}{\partial a} > 0$. At this point, as environmental regulation intensifies, the level of the firm's production technology rises. When $\alpha\in[0.5\ 1]$, $\left[\frac{\partial W}{\partial F}(1-2a)\right]\bullet f < 0$, because $T'(T_A, \cdot)>0$, then $\frac{\partial T_A}{\partial W} + \frac{\partial T_E}{\partial W} < 0$. At this time, if manufacturers choose green technology to reduce pollution emissions, then $\frac{\partial T_E}{\partial W} < 0$. Therefore, there are two cases in which either $\frac{\partial T_A}{\partial W} < 0$ or $0 < \frac{\partial T_A}{\partial W} < -\frac{\partial T_E}{\partial W}$, when $\frac{\partial T_A}{\partial W} < 0$, $\frac{\partial T_A}{\partial a} = \frac{\partial T_A}{\partial W}\cdot\frac{\partial W}{\partial a} > 0$. At the time, as the intensity of environmental regulation rises, manufacturer pollution emissions fall and the level of production technology rises. When $0 < \frac{\partial T_A}{\partial W} < -\frac{\partial T_E}{\partial W}, \frac{\partial T_A}{\partial a} < 0$, as the intensity of environmental regulation increases, pollution emissions by the firm decline, and the level of production technology of the firm also declines. Based on the actual situation, when companies choose green technology, it will cost them inputs of production technology. Since a decline in production technology appears to be a reasonable result of green technology choices, we choose to analyze a decline in production technology. When manufacturers select production technology,

$\frac{\partial T_A}{\partial W} = \frac{\partial T_A}{\partial E_A} \bullet \frac{\partial E_A}{\partial W} < 0$, $\frac{\partial T_A}{\partial a} = \frac{\partial T_A}{\partial W} \cdot \frac{\partial W}{\partial a} > 0$. At present, when the intensity of environmental regulation rises, the level of production technology of the firm increases. This shows that when α∈ [0.5 1], if manufacturers choose green technology to reduce pollution emissions, as the intensity of environmental regulation rises, the level of production technology of the enterprise declines. If manufacturers use production technology changes to reduce emissions, then, as the intensity of environmental regulation increases, the level of production technology of the enterprise rises.

Within α∈ [0 1] range, as the intensity of environmental regulation rises, if manufacturers use production technology changes to reduce pollution emissions, the level of production technology of the firm rises. Conversely, if manufacturers use green technology to reduce pollution emissions, the level of production technology of the enterprise falls. In the actual decision-making of manufacturers, due to utility maximization and the law of diminishing marginal utility of innovation, manufacturers often choose not to use production technology enhancement to reduce pollution emissions. If manufacturers first choose the green technology, and then select production technology, the relationship between production technology progress and the intensity of environmental regulation exhibits a U-shaped curve. If the manufacturers choose to first change production technology, and then turn to green technology, the relationship between production technology progress and the intensity of environmental regulation exhibits an inverted U-shaped curve. If manufacturers simultaneously use both kinds of technology to reduce pollution emissions, the relationship between technological progress and environmental regulation is not significant.

Based on the foregoing analysis, we argue that as the intensity of environmental regulations grows, due to manufacturer choice of different technologies to reduce pollution emissions, the relationship between the intensity of environmental regulation and production technology progress of manufacturers should be one of three types: a U-shaped relationship, an inverted U-shaped relationship, and no significant relationship.

Empirical Model and Data Sources

Empirical Model

After analyzing the relationship between the intensity of environmental regulations and production technology progress, we determine the form of the empirical model. Because technology progress affects early stage technology, we tested the variable data using the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) and found a first-order lag in technological progress but no second-order lag in the empirical model. Hence, the model appears to be a dynamic panel model. We used RESET to test the variable data and found that in the model, the variability of the intensity of environmental regulation has a quadratic form. In addition, we follow the existing literature in estimating a reduced-form regression [1, 18], which takes the form:

$$TECH_{it} = \beta_0 + \beta_1 TECH_{it-1} + \beta_2 ER_{it} + \beta_3 ER_{it}^2 + \beta_4 \eta_{it} + \upsilon_{it} + \varepsilon_{it}$$

...where *i* denotes industries and *t* represents years. *TECH* is a measure of production technological progress and ER_{it} is a measure of the intensity of environmental regulations. η_{it} is a set of control variables constructed in this paper. The following section discusses in detail the various alternative proxy variables used.

Estimation Methodology

We use the generalized method of moments (GMM) estimators developed for dynamic models of panel data. These models include lags of the dependent variable as covariates, and contain unobserved individual-level effects (fixed or random). A consistent GMM estimator of dynamic panel models was derived by Arellano and Bond [23].

When the new instrumental variable is effective, the system GMM estimation should be more effective than different GMM estimations. From Tables 3-5, the results of Breusch-p test, and the DWH test, we can draw the conclusion that the variables of the econometric model are endogenous and heteroscedastic. Hence, it is possible to use the two-step GMM estimator, which allows for more efficient estimation than the one-step. However, in finite samples, the two-step estimator generates standard errors that are biased downwards. We correct for this using the standard errors proposed by Windmeijer [24]. These standard errors permit heteroscedasticity in the underlying error ε_{it}.

Data Sources

In this paper we use a provincial panel data of 17 industries in China from 2000 to 2011 as our research samples. Our primary data sources are the *China Statistical Yearbook*, the *China Industrial Economic Statistical Yearbook*, the *Municipal and Provincial Statistical Yearbook*, the *China Science and Technology Yearbook*, the *China Environment Yearbook*, and the *China Environment Statistical Yearbook*. The variables we used in the model include the following: production technological progress, the intensity of environmental regulation; and control variables. The variables are discussed in greater detail below.

Production Technological Progress

We use the method of the stochastic frontier beyond the logarithmic production function to calculate the production technology progress rate of industrial departments in 30 provinces (except Tibet) of China to measure the progress of production technology. In order to achieve the purpose, we need the input and output data of the industrial sectors of the individual provinces. We selected the gross output value of industrial firms above a designated size as the output. In order to assess the robustness of our results, we

Table 1. Summary statistics of variables.

Variable	Variable code	Observations	Mean	Std. Dev	Minimum	Maximum
Production technology progress	TECH	6120	0.177	0.033	0.0006	0.521
Environmental regulation intensity	ER	360	3.094	10.786	0.073	132.94
Pollution intensity	PACE	360	0.035	0.034	0.002	0.196
Human capital	SHC	360	8.277	0.952	5.968	11.555
Ownership structure	OS	360	0.610	0.191	0.135	0.951
Economic development level	DED	360	8.449	1.025	5.489	10.787
Openness	OPEN	360	6.838	1.731	2.587	10.911
Investment in science and technology	IST	360	11.731	1.278	8.480	15.223

deflate the data using industry-specific price deflators to obtain a real series. Capital investment is usually measured by capital stock, but there is no data on capital stock in China. Instead, we use the stock of fixed capital. Because the statistical data published by Chinese officials gives the annual net value of fixed assets, we can obtain the annual fixed capital increment through the net value of fixed capital obtained by subtracting adjacent years from each other. We deflate this data using the price index of fixed asset investment to obtain a real series. We then add the fixed assets of the most recent year to the above data to obtain the stock of fixed capital for a given year [25]. The data of 2004 was averaged using 2003 and 2005, due to the lack of data in 2004. Generally speaking, labor input should be expressed using labor time. However, since this data is not available, we use the annual average number of employed personnel of the firms above a designated size instead of labor time.

Intensity of Environmental Regulation

For measurement of the intensity of environmental regulation, scholars usually use the cost to the firm as the indicator. However, such costs vary with the differing production scales of firms. Therefore, the difference in production scale must be considered when measuring the intensity of environmental regulation. Hence, in this study the pollution treatment cost per 1,000 Yuan of industrial output value is used as the measure of the intensity of environmental regulation, calculated via (pollution treatment – the industrial production) ×1000. The pollution control costs are obtained using provincial pollution treatment project investment data [11].

Control Variables

We include a variety of control variables that have been shown elsewhere to be important determinants of production technological progress. First, we use openness as a control variable. Industry exposure to foreign competition can affect production technological progress. One argument is that strong competition from abroad will give manufacturers a greater incentive to reduce costs, thereby encouraging production technological innovation. Hence we include the openness of the sector to trade, measured as the ratio of total exports and imports with gross domestic product (GDP). Second, we include the level of economic development as a determinant of production technological progress. We measure this through per capita GDP. In order to maintain comparability of statistical data, we deflate the statistical data using the GDP deflator. Third, we include human capital, which is an important factor influencing technological progress. Education level is used to measure the level of human capital, where human capital stock is defined as the product of the number of workers and their human capital level. We use average education in years per worker in this calculation. Average education in years is obtained using the following method. We take the average education level of the population age 6 and over to represent the level of human capital, and assume that years of schooling for all levels of educational are: illiterate 0 years, primary school 6 years, junior high school 9 years, high school 12 years, and college and over 16 years. Then the average education years = proportion of primary school× 6 + proportion of junior middle school× 9 + proportion of high school×12 + proportion of college degree and above×16. Finally, we use the results of this calculation to measure human capital [26].

Fourth, investment in science and technology is an important factor in technological progress. We use the gross expenses for internal research and development institutions to measure the investment in science and technology. In order to maintain comparability of statistical data, we deflate the statistical data using the retail price index. Fifth, we include the ownership structure as a control variable because it has an effect on production technology progress. For example, Zhang argued that ownership structure has a negative role on production technology progress [20]. As indicators of ownership structure, we use figures for the total assets of state-owned and state held firms in proportion to industrial firms above a designated size. Sixth, we include pollution intensity as a determinant of production technological progress. Some researchers have argued that pollution intensity affects the region's selection of skilled workers, thus affecting technological progress. There are

Table 2. Two-step system GMM estimates of production technology progress of low polluting industries.

Explanatory variables	H32	H33	H11	H29	H19
L.TECH	0.854*** (0.039)	0.168*** (0.038)	0.789*** (0.038)	0.107*** (0.033)	0.343*** (0.045)
ER	-0.001 (0.001)	-0.015*** (0.003)	-0.001 (0.001)	0.007*** (0.002)	0.006** (0.002)
ER2	0.001 (0.001)	0.001*** (0.001)	0.001 (0.001)	-0.001*** (0.001)	-0.001** (0.001)
PACE	-0.017 (0.027)	-1.751*** (0.299)	-0.411*** (0.090)	-0.775*** (0.211)	-0.091*** (0.256)
L.SHC	0.002*** (0.001)	0.052*** (0.006)	-0.002 (0.001)	0.314*** (0.003)	0.013*** (0.003)
L.OS	0.045*** (0.014)	0.346*** (0.050)	0.036** (0.017)	-0.117*** (0.028)	-0.006 (0.038)
L.lnDED	0.006** (0.003)	0.269*** (0.046)	0.055*** (0.015)	0.056*** (0.016)	0.232*** (0.019)
L. lnOPEN	0.001 (0.003)	0.029 (0.020)	0.006 (0.006)	0.014* (0.007)	0.016 (0.015)
L.lnIST	0.003** (0.002)	0.079*** (0.014)	0.012* (0.007)	0.034*** (0.006)	0.069*** (0.016)
Constant term	0.053** (0.02)	0.607*** (0.167)	0.213*** (0.051)	0.195* (0.103)	-0.419* (0.213)
Observations	330	330	330	330	330
Breusch-p test	1.22 (0.550)	3.56 (0.168)	4.72 (0.094)	5.65 (0.059)	3.31 (0.191)
DWH test	30.23 (0.00)	36.79 (0.00)	40.45 (0.00)	59.32 (0.00)	233.38 (0.00)
AR (1)	0.025	0.049	0.016	0.048	0.001
AR (2)	0.239	0.800	0.200	0.855	0.321
Sargan test	0.98	0.122	0.221	0.98	0.91

two main methods for measuring pollution intensity, the pollution emissions per unit of output and calculating the spending on pollution management and control per unit of output [27]. In this paper we use the first method and use the ratio of sulfur dioxide emissions of firms within each province to industrial added value to measure pollution intensity.

Estimation Results and Analysis

Estimation Results

We estimated the production technology progress of the 17 industries and divided them into three categories: low polluting industries, medium polluting industries, and heavily polluting industries. The estimation results are shown in Tables 2-4.

In Tables 2-4, we adopt the two-order serial correlation (AR (2)) test and Sargan test to investigate the model design and the selection of the instrumental variables. The results of the AR (2) test show that estimation error does not exist in the two-order sequence correlation. The results of the Sargan test also show that the selection of the instrumental variables is reasonable.

Regression Results Analysis

Tables 2-4 show that the intensity of environmental regulation does not have the same degree of impact on pro-

Table 3. Two-step system GMM estimates of production technology progress of medium-polluting industries.

Explanatory variables	H22	H28	H8	H10	H21	H9	H27
L.TECH	-0.111**	-0.237***	-0.198***	0.984***	0.049	-0.273***	1.020***
	(0.045)	(0.034)	(0.024)	(0.004)	(0.037)	(0.023)	(0.014)
ER	-0.024***	-0.003***	0.006	0.001***	0.002	0.005**	0.001***
	(0.07)	(0.001)	(0.004)	(0.001)	(0.001)	(0.002)	(0.001)
ER2	0.001***	0.001**	-0.001	-0.001***	0.001	-0.001**	-0.001***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
PACE	-0.783**	-0.795***	-0.248	-0.001	-0.678***	-0.995***	0.026
	(0.421)	(0.147)	(0.236)	(0.001)	(0.155)	(0.125)	(0.023)
L.SHC	0.077***	0.032***	0.098***	0.002***	0.052***	0.069***	0.004***
	(0.010)	(0.003)	(0.006)	(0.001)	(0.004)	(0.003)	(0.001)
L.OS	0.753***	0.199***	-0.567***	-0.002***	-0.287***	-0.322***	-0.025***
	(0.135)	(0.024)	(0.083)	(0.001)	(0.052)	(0.045)	(0.005)
L.lnDED	0.171***	0.079***	0.043	0.001	0.149***	0.003	0.006
	(0.057)	(0.008)	(0.038)	(0.001)	(0.016)	(0.015)	(0.004)
L.lnOPEN	0.020	-0.002	0.049**	0.003***	0.022**	0.023**	0.004***
	(0.025)	(0.007)	(0.022)	(0.001)	(0.009)	(0.009)	(0.001)
L.lnIST	0.078***	0.006	0.014	0.001	0.030***	0.009	0.002*
	(0.026)	(0.007)	(0.017)	(0.001)	(0.008)	0.009	(0.001)
Constant term	-0.924***	0.204***	0.615***	0.011***	0.335***	0.215**	-0.024**
	(0.323)	0.062	(0.164)	(0.003)	(0.081)	(0.094)	(0.011)
Observations	330	330	330	330	330	330	330
Breusch-p test	2.81	6.03	3.27	1.23	4.70	5.40	2.80
	(0.246)	(0.051)	(0.196)	(0.542)	(0.096)	(0.067)	(0.250)
DWH test	39.76	67.89	78.54	57.40	43.23	53.13	42.12
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
AR (1)	0.085	0.008	0.007	0.037	0.002	0.012	0.003
AR (2)	0.781	0.218	0.20	0.118	0.712	0.134	0.168
Sargan test	0.98	0.30	0.58	0.970	0.280	0.451	0.47

duction technology progress across different industries and industries with different levels of pollution.

In a low polluting industry such as machinery and equipment manufacturing or the textile industry, the intensity of environmental regulation has a negative but not significant effect on production technology progress. On communications equipment, computers, and other electronic equipment manufacturing industries it is significantly negative. On the general equipment manufacturing industry and petroleum processing and coking industries it has a significantly positive effect.

For medium polluting industries such as the chemical fiber manufacturing industry and the metal products industry, the intensity of environmental regulation has a significantly negative effect on the production technology progress of industries. Its effect on the food manufacturing and pharmaceutical industries is positive but not significant. The impact of intensity of environmental regulation on the tobacco, beverage manufacturing, and non-ferrous metal smelting, rolling, and processing industries is significantly positive. For heavily polluting industries, the intensity of environmental regulation has a significantly negative effect on the production technology progress of industries such as non metallic mineral products, coal, and paper and paper products industries. Its effect on the ferrous metal smelting, rolling, and processing, and chemical raw materials and chemical products manufacturing industries is significantly positive. Clearly the effect of environmental regulation on production technology progress varies across industries with differing levels of pollution.

Table 4. Two-step system GMM estimates of production technology progress of heavily polluting industries.

Explanatory variables	H25	H26	H20	H1	H16
L.TECH	1.001***	0.382***	0.058	-0.125***	0.996***
	(0.017)	(0.056)	0.051	(0.018)	(0.045)
ER	-0.001*	0.011***	0.002***	-0.012**	-0.001*
	(0.001)	(0.003)	(0.001)	(0.005)	(0.001)
ER2	0.001	-0.001***	-0.001***	0.001**	0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
PACE	0.008	-1.445***	-0.265***	-1.245***	-0.003
	(0.022)	(0.288)	(0.050)	(0.439)	(0.022)
L.SHC	0.001	0.051***	0.010***	0.099***	0.003***
	(0.001)	(0.004)	(0.001)	(0.008)	(0.001)
L.OS	-0.001	-0.233***	-0.048***	0.417***	-0.022***
	(0.001)	(0.036)	(0.001)	(0.069)	(0.007)
L.lnDED	0.009***	0.203***	0.032***	0.052**	0.004
	(0.002)	(0.026)	(0.004)	(0.036)	(0.006)
L.lnOPEN	0.001	0.032**	0.005*	0.040*	0.003
	(0.001)	(0.016)	(0.003)	(0.020)	(0.002)
L.lnIST	0.002	0.052***	0.009***	0.027	0.003**
	0.001	(0.014)	(0.003)	(0.018)	(0.002)
Constant term	0.011	-0.095	0.077***	0.325	0.007
	(0.013)	(0.149)	(0.028)	(0.232)	(0.017)
Observations	330	330	330	330	330
Breusch-p test	2.44	3.31	5.09	3.84	3.28
	(0.295)	(0.191)	(0.079)	(0.146)	(0.194)
DWH test	39.03	48.55	39.01	87.35	35.43
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
AR (1)	0.001	0.036	0.052	0.012	0.004
AR (2)	0.660	0.841	0.921	0.301	0.054
Sargan test	0.408	0.151	0.782	0.698	0.627

Industry code: H32 – electrical machinery and equipment manufacturing, H33 – communication equipment, computers, and other electronic equipment manufacturing industries, H11 – textiles, H29 – general equipment manufacturing industry, H19 – oil processing and coking industry enterprises, H25 – non-metallic mineral products, H26 – black metal smelting, rolling, and processing industries, H20 – chemical raw materials and products manufacturing, H1 – coal industry enterprises, H16 – paper and paper products, H22 – chemical fiber industry, H28 – fabricated metal products, H8 – food manufacturing, H10 – tobacco products, H21 – pharmaceutical manufacturing, H9 – beverage manufacturing, H27 – non-ferrous metal smelting, rolling, and processing industries.
Classification of industries by pollution level are based on Zhao [28].
Sargan is a test of overidentifying restrictions. Standard errors are Windmeijer WC-robust. All variables are in levels.
*Significance at the 10% level. **Significance at the 5% level. *** Significance at the 1% level.

Next, we analyze the relationship between the intensity of environmental regulation and the production technology progress of different industries. Based on the data in Tables 3-5, we form three categories for analysis.

Firstly, the coefficients of the variable of the intensity of environmental regulation of industries such as communications equipment, computers, and other electronic equipment manufacturing, chemical fiber manufacturing, metal products, and coal industries were positive and negative, respectively, and statistically significant. This shows that with an increase in the intensity of environmental regulation, the production technology progress of the industries will first decline and then rise. Thus, there appears to be a "U"-shaped relationship between the intensity of environmental regulation and production technology progress. We argue that because the production technology level of these industries is higher, when the environmental regulation increases slowly, pollution reduction is more costly than green technology for firms. Therefore, initially these industries will use green technology to reduce pollution emissions. Furthermore because technology research is a slow process, and the firm reacts passively to environmental regulations, manufacturers may at first divert capital for producing technological innovation for pollution control, reducing progress in production technology.

In the long run, if the government raises the intensity of environmental regulation to the inflection point of the U-shaped curve, the number of manufacturers will fall, market concentration will increase, and the surviving manufacturers tend to attach greater importance to technological innovation. Under the law of diminishing marginal performance of technological innovation of pollution treatment, firms will increase their investment in production technology research and development in order to improve productivity, output and profit first, then from the added profits take out money for pollution control to meet the government's higher environmental regulation requirements. Therefore, as the intensity of environmental regulation continues to rise, the production technology level begins to ascend. Thus, the intensity of environmental regulation and production technology progress has a U-shaped trajectory [20].

Secondly, in general equipment manufacturing, oil processing and coking, tobacco, beverage manufacturing, nonferrous metal smelting, rolling, and processing, ferrous metal smelting, rolling, and processing, and chemical raw materials and chemical products manufacturing industries, the intensity of environmental regulation coefficients of the variables are both positive and negative, and statistically significant. Thus shows that a moderate intensity of environmental regulation will promote industry production technology progress, but if the intensity of environmental regulation exceeds a certain limit, it will restrain production technology progress. The relationship between the intensity of environmental regulation and production technological progress in these industries is thus an inverted U-shaped relationship. We argue that because the level of production technology is low, when environmental regulation increases slowly, industries can easily raise their level of production technology to reduce production emissions. Hence firms will choose to improve production technology, leading to progress in production technology as environmental regulation tightens. But when the intensity of environmental regulation exceeds a certain limit, firms are under pressure and green improvements become costlier in terms of manpower, resources, and funds. This demand for green technological improvement will “crowd out” research into production technology, resulting in a loss of production technology progress. Thus, the relationship between the intensity of environmental regulation and production technological progress in these industries exhibits an inverted U shape.

Third, for other industries such as machinery and equipment manufacturing, textiles, food manufacturing, pharmaceutical, non-metallic mineral products, and the paper and paper products industries, the environmental regulation intensity variable coefficients is also both positive and negative, but is not significant. There is thus no obvious U-shaped relationship between the intensity of environmental regulation and production technology progress. This is likely because these industries face changing intensity of environmental regulation and use a combination of approaches involving both production technology and green technology improvement to reduce pollution emissions. The relationship between production technology progress and environmental regulation appears to be associated not only with the degree of tightness of environmental regulation measures, but also with the form of environmental regulation [29].

For the six control variables, the level of effect and significance of each control variable for the production technology progress of each industry is also inconsistent. The influence of pollution-intensive degree on the progress of production technology of some industries such as ferrous metal smelting, rolling, and processing, non-metallic mineral products, machinery and equipment manufacturing, and food manufacturing industries, is not significant, while for the communications equipment, computers, and other electronic equipment manufacturing, textile, general equipment manufacturing, oil processing and coking, chemical fiber manufacturing, metal products, tobacco, pharmaceutical, beverage manufacturing, ferrous metal smelting, rolling, and processing, chemical raw materials and chemical products manufacturing, coal, and paper and paper products industries, it is significantly negative. This shows that pollution intensivity inhibits production technological progress. This conclusion is consistent with Kyriakopoulou, who contended that pollution affects the concentration of skilled workers, further affecting technological progress [30].

The influence of ownership structure on the production technology progress of the coal, machinery and equipment manufacturing, communications equipment, computers and other electronic equipment manufacturing, textile, chemical fiber manufacturing, and metal products industries is significantly positive. This shows that in China these industries have technological advantages. A high level of nationalization is thus conducive to the progress of production technology. The effect of ownership structure on the production technology progress of other industries such as the tobacco, pharmaceutical, beverage manufacturing, ferrous metal smelting, rolling, and processing, non-metallic mineral products, ferrous metal smelting, rolling, and processing, chemical raw materials and chemical products manufacturing, paper and paper products, general equipment manufacturing, and food manufacturing industries, are significantly negative. In these industries the speed of technological progress of state-owned and state-held enterprises remains relatively slow compared to that of foreign invested enterprises, foreign-funded enterprises, and private enterprises. Based on the regression results, the impact of human capital stock, the degree of economic development, openness, and the input of science and technology on technology progress are all positive, which is consistent with the conclusions of Fan [31].

Conclusions and Policy Implications

We analyzed provincial panel data from 2000 to 2011 using a dynamic panel-data GMM estimation method to investigate the effect of the intensity of environmental regulation on production technology progress in 17 industries. Our findings are as follows.

First, from the empirical results show that the relationship between the progress of production technology and environmental regulation intensity is not a simple U-shaped curve. For some industries such as the communications equipment, computers and other electronic equipment manufacturing, chemical fiber manufacturing, metal products, and coal industries the relationship is U-shaped, while for others such as general equipment manufacturing, oil processing and coking, tobacco, beverage manufacturing, non-ferrous metal smelting, rolling, and processing, ferrous metal smelting, rolling, and processing, and chemical raw materials and chemical products manufacturing industries, the relationship is an inverted U. For still others, such as machinery and equipment manufacturing, textile, food manufacturing, pharmaceutical, non metallic mineral products, paper and paper products, there is no obvious U-shaped relationship.

Second, after dividing the 17 industries into low, medium, and heavily polluting industries, we found that the effect of environmental regulation intensity on the production technology progress of the identically polluting industries is different. This appears to show that there is no relationship between the impact of environmental regulation on industry production technology progress and level of pollution.

Policy Implications

First, the government of China should take into account the production technology progress in the affected industries when increasing the intensity of environmental regulation, and vary the strength of regulation across different industries. For the communications equipment, computers and other electronic equipment manufacturing, chemical fiber manufacturing, metal products, and coal industries, the government should rapidly develop and implement strict environmental regulation in order to break through the inflection point of the U-shaped curve as soon as possible. This will promote the progress of production technology in those industries. For general equipment manufacturing, oil processing and coking, tobacco, beverage manufacturing industry, non-ferrous metal smelting, rolling, and processing, ferrous metal smelting, rolling, and processing, chemical raw materials and chemical products manufacturing industries, the government should be slow to raise the environmental regulation intensity and try to avoid crossing the inflection point of the inverted U-shaped curve, which would reduce production technology progress in those industries. For the other industries evaluated in this study, because the effect of environmental regulation intensity on the progress of production technology is not significant, the government can loosen or tighten regulations based on other policy requirements.

Second, because the influence of pollution intensivity on the progress of production technology is negative, the government should reduce regional pollution intensivity to promote the progress of production technology. The effect of ownership structure on the progress of production technology of some industries such as the coal, machinery and equipment manufacturing, communications equipment, computers and other electronic equipment manufacturing, textile, chemical fiber manufacturing, and metal products industries is significantly positive. Therefore, we argue that the government should increase the degree of nationalization of these industries to promote the progress of production technology. For the tobacco, pharmaceutical, beverage manufacturing, ferrous metal smelting, rolling, and processing, non metallic mineral products, ferrous metal smelting, rolling, and processing, chemical raw materials and chemical products manufacturing, paper and paper products, general equipment manufacturing, and food manufacturing industries, the influence of ownership structure on the progress of production technology is significantly negative. Therefore, we advise the government to reduce the proportion of state-owned capital in these industries. Finally, increasing investment in science and technology, and improving the stock of human capital and economic growth will also promote production technology progress.

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