Environmental Regulation, Technological Innovation and Industrial Environmental Efficiency:An Empirical Study Based on Chinese Cement Industry

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Environmental Regulation, Technological Innovation and Industrial Environmental Efficiency:An Empirical Study Based on Chinese Cement Industry

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Abstract

Using DEA-Tobit model, the paper empirically analyzes the impact of environmental regulation and technological innovation on industrial environmental efficiency with the data from Chinese Cement Industry. The results show that both environmental regulation and technological innovation all have a significant role in promoting the environmental efficiency of cement industry. Among all the influencing factors, the improvement of pollution disposal capacity has the biggest positive effect on environmental efficiency, while the energy-saving effect caused by environmental regulation is not obvious, the factor endowment structure has no substantial impact on environmental efficiency. Adhering to the strategy of "reducing emissions mainly and saving energy as auxiliary", continuously optimizing the energy consumption structure, raising the level of industrialization and industrial agglomeration are conducive to the sustainable development of China’s cement industry.

Key Words

Environmental Regulation; *Technological Innovation*; *Environmental Efficiency*; *Chinese Cement Industry*

1 Introduction

Cement industry is closely related to production, construction and people's life, and its output value accounts for 40% of the building materials industry. China is not only a big country in cement production, but also a big country in cement consumption. In 2019, China's cumulative cement output will reach 2.33 billion tons, accounting for more than 50% of the global total cement output. However, as a traditional industrial sector, cement manufacturing industry has typical production characteristics of high energy consumption, high emission and resource dependence, which inevitably brings a series of environmental pollution problems. Dust particles are the most important pollutants in the process of cement preparation, followed by SO_2, NO_x, CO_2 and other harmful gas emissions. NO_x is an important reason for the formation of photochemical smog and acid rain, and also an important source of PM2.5. As the largest emission of dust, cement manufacturing has become a key area of national environmental regulation, and it is urgent for the state to formulate scientific regulatory policies. Based on this, this paper selects the heavily polluted cement manufacturing industry as the research object, empirically analyzes the influencing factors of environmental efficiency of cement manufacturing industry and their influence degree, systematically displays the influence process and results of environmental regulation on environmental efficiency, and provides decision support for promoting the sustainable development of China's cement manufacturing industry.

2 Literature Review

According to the constraints of output set function, there are four different choices to improve environmental efficiency: (1) under the condition of certain unexpected output, maximize expected output and minimize factor input; (2) Under the condition of certain factor input, the expected output is maximized and the unexpected output is minimized; (3) Under the condition of certain expected output, the unexpected output and input factors are minimized; (4) At the same time, it maximizes the expected output. No matter which way is adopted, enterprises either passively increase investment in pollution control, or actively carry out technological upgrading to achieve the set goal of increasing production and reducing pollution. On the surface, pollution end treatment can significantly improve the environmental risk faced by enterprises, but it also increases the production cost of enterprises, resulting in the reduction of production of "good" products, which may not necessarily promote the improvement of environmental efficiency in the short term. As a result, as a rational producer, it may be more inclined to choose the latter, through the technical transformation of the existing production process to improve the output efficiency of resources, reduce hazardous waste emissions, and fundamentally improve the environmental efficiency of enterprises.It can be seen that environmental regulation and technological innovation are the two main factors affecting environmental efficiency. On the one hand, the government can control the emission of harmful pollutants by strengthening environmental regulations, and urge enterprises to passively improve environmental efficiency; On the other hand, enterprises can take the initiative to carry out technological innovation activities to optimize their own environmental behavior, so as to avoid the environmental risk brought by government regulation.

As a traditional industrial sector, cement manufacturing industry has obvious production process characteristics of high energy consumption, high emission and resource dependence, which will inevitably bring a series of environmental pollution problems. Unfortunately, the existing literature research rarely involves the environmental efficiency of cement industry. For example Oggioni *et al*. analyzed the eco-efficiency of 21 prototypes of cement industry using DDF approach. Riccardi *et al.* assessed the efficiency of the high energetic and CO_2 emissions intensive cement production processes in 21 countries using distance function and directional distance function. Long *et a*l. investigated total factor productivity eco-efficiency and the determinants of Malmquist in China's cement manufacturers. Zhang *et al*. analyzed the environmental efficiency of China's listed cement companies using a non-radical DEA model with slacks-based measure.

From the discussion above, we understand that more research focuses on the 3E problem at the macro level. However, enterprise organizations are the objects of national environmental regulation and the executors of regulatory policies. Therefore, it is necessary to analyze the problem of environmental efficiency from the level of industry and enterprise. Based on the above theoretical analysis, this paper believes that environmental regulation and technological innovation can help to improve the environmental efficiency of cement manufacturing industry as a whole. Following the environmental regulation can improve the environmental efficiency, and the improvement of environmental efficiency itself can bring some potential economic benefits to the regulated, so as to realize the indirect transmission mechanism of environmental regulation.

3 Research Design

3.1. Variable Measurement

Environmental efficiency: Environmental efficiency is an important indicator to describe the coordinated development of energy, environment and economy. The paper uses the directional distance function model proposed by chambers and Chung *et al*. to measure the environmental efficiency score.

$$ETE(*) = 1/\left[1 + \vec{D}_0^{\omega}(*)\right] \quad (1)$$

In the above formula, $ETE(*)$ represents the environmental efficiency score, and $\vec{D}_0^{\omega}(*)$ is the optimal solution of directional environmental distance function. When the actual output is infinitely close to the output frontier, $\vec{D}_0^{\omega}(*)$ is close to 0 and $ETE(*)$ is close to 1, the environmental technology is the most efficient. Due to the influence of various uncontrollable factors, the actual output can only be located below the output front, so the environmental efficiency score between 0 and 1 becomes a limited dependent variable.

Environmental regulation intensity: Reducing pollutant emission concentration is not the most direct way to improve environmental efficiency. Previous studies have shown that controlling the total amount of pollutant emission, improving the removal rate of harmful substances and the standard emission rate will have the most direct impact on the improvement of environmental efficiency. In this paper, *ERI*(1) is used as the proxy variable of environmental regulation intensity. In order to enhance the reliability of the research conclusions, *ERI*(2) is set to test the robustness of panel data. The calculation formulas are as follows:

$$ERI(1)_{i,t} = SDrem_{i,t} / \left(SDrem_{i,t} + SDemi_{i,t}\right) \quad (2)$$

$$ERI(2)_{i,t} = SO_2semi_{i,t} / SO_2\,emi_{i,t} \quad (3)$$

In the above formula, $ERI(1)_{i,t}$ and $ERI(2)_{i,t}$ represent the dust removal rate and sulfur dioxide emission rate of cement manufacturing industry respectively. $SDrem_{i,t}$ and $SDemi_{i,t}$ in formula 2 represent the amount of smoke (dust) removal and total emission of cement manufacturing industry respectively, $SO_2semi_{i,t}$ and $SO_2emi_{i,t}$ in Formula 3 represent the amount of sulfur dioxide up to standard and total emission of cement manufacturing industry respectively. *ERI*(1) and *ERI*(2) are both used to measure the severity of environmental regulation. The higher the value is, the more severe the environmental regulation is, and the better the effect of environmental regulation is, and vice versa.

Technological innovation ability: Technological innovation results not only show the increase of tangible or intangible output, but also show the improvement of environmental efficiency. Technological innovation is an important factor affecting environmental efficiency. When measuring the technological innovation ability, we select two indicators, namely R&D funds and R&D personnel input intensity, to comprehensively reflect the financial and human input in R&D activities of China's cement manufacturing industry.

Control variables: There are many factors that affect environmental efficiency. Based on previous studies, this paper selects asset liability ratio, return on equity, growth opportunities and enterprise size as control variables. In addition, the dummy variables of region and year are set to control the impact of macroeconomic environment changes related to region and time. The symbols and definitions of variables are shown in Table 1.

Insert table 1 here

3.2. DEA Tobit Two-stage Analysis Method

As the environmental efficiency is a limited dependent variable, this paper uses the maximum likelihood estimation method of Tobit random effect model to investigate the influencing factors of the environmental efficiency of China's cement manufacturing industry and their influence degree, and constructs the Tobit regression models of national panel data and regional panel data respectively.

$$\begin{aligned} ETE^{*}_{i,t} &= C + \beta_1 ERI(j)_{i,t} + \beta_2 ERI(j)_{i,t-1} + \beta_3 R\&D-M_{i,t-1} + \beta_4 R\&D-P_{i,t-1} \\ &+ \beta_5 EC_{i,t-1} + \beta_6 ES_{i,t-1} + \beta_7 DI_{i,t-1} + \beta_8 Size_{i,t-1} + \beta_9 \sum \mathrm{Re}gion \\ &+ \beta_{10} \sum Year + \varepsilon_t; \qquad ETE_{i,t} = Max\left(0, ETE^{*}_{i,t}\right) \end{aligned} \tag{4}$$

$$\begin{aligned} ETE^{*}_{i,t} &= C + \beta_1 ERI(j)_{i,t} + \beta_2 ERI(j)_{i,t-1} + \beta_3 R\&D-M_{i,t-1} + \beta_4 R\&D-P_{i,t-1} \\ &+ \beta_5 EC_{i,t-1} + \beta_6 ES_{i,t-1} + \beta_7 DI_{i,t-1} + \beta_8 Size_{i,t-1} \\ &+ \beta_9 \sum Year + \varepsilon_t; \qquad ETE_{i,t} = Max\left(0, ETE^{*}_{i,t}\right) \end{aligned} \tag{5}$$

Where j is equal to 1 or 2, both are used to measure the intensity of environmental regulation. When j=1, it means the removal rate of smoke (dust) in cement manufacturing industry, and when j=2, it means the standard emission rate of sulfur dioxide in cement manufacturing industry, which is used for robustness test. In order to avoid the influence of endogenous problems on the estimation results, the relevant variables in the equation lag one period to enter the equation.

3.3. Data Source Description

This paper selects the balanced panel data of cement manufacturing industry in 30 provinces and autonomous regions of China from 2004 to 2016, and uses the data of 2002 and 2003 as the lag term of relevant variables. The variable data mainly comes from the statistical data of cement manufacturing industry in China cement Yearbook and digital cement network, China Statistical Yearbook, China Environment Yearbook, China energy statistical yearbook and China Science and technology statistical yearbook, which are manually processed.

4 Empirical results and analysis

4.1. Descriptive Statistics of Main Variables

Table 2 gives the descriptive statistics of the main variables. From the national statistical data, the average of environmental efficiency is 0.8884, the maximum is 1, and the minimum is 0.524. The overall level of environmental efficiency of cement manufacturing industry is not high, and there are great differences in environmental efficiency of cement manufacturing industry in different provinces. The average values of *ERI*(1) and *ERI*(2) are 87.35% and 76.64% respectively, which indicates that the control effect of cement manufacturing industry on smoke (dust) is better than that on sulfur dioxide. As the main pollutant of cement industry, there is still much room for sulfur dioxide emission reduction. From the regional statistical data, the average environmental efficiency of cement manufacturing industry in the eastern and central regions has reached more than 0.9, while the average environmental efficiency of cement manufacturing industry in the western region is only 0.8159, far lower than the national average. The results show that *ERI*(1) and *ERI*(2) are gradually increasing in the west, middle and East. The average of dust removal rate and sulfur dioxide emission rate of cement manufacturing industry in the eastern region are more than 90%. The cement manufacturing industry in the eastern region is obviously better than the central and western regions in pollution control, and the environmental regulation is also more serious Strict.

Insert table 2 here

4.2. Correlation Coefficient Test

Before the regression analysis, the correlation coefficient test of variables was carried out. It was found that except for the strong correlation between *ERI*(3) and *ERI*(4), the correlation coefficients of other variables were not large, indicating that the collinearity problem between variables was not serious. In addition, we use the variance expansion factor method to diagnose the multicollinearity of each variable. The test results show that the tolerance of each variable is greater than 0.264, and the variance expansion factor VIF is controlled within 4, so the problem of multicollinearity between variables is not serious.

Insert table 3 here

4.3. Regression Analysis

Call the xttobit package provided by Stata11.0 to complete the parameter estimation process. The Tobit estimation results of national panel data and regional panel data are shown in tables 4 and 5 below. In models 1, 3 and 5 of the two tables, *ERI*(1) is selected as the proxy variable of environmental regulation, and *ERI*(2) is used as the standard emission rate of sulfur dioxide under the same conditions, and hierarchical regression method is used for robustness test.

1.Regression analysis of national panel data

It can be seen from the estimation results in Table 4 that the fitting effect of the model is ideal, and the contribution of the panel variance component to the total variance in the six models is more than 0.8, indicating that the change of environmental efficiency is mainly explained by its individual effect. The chi square statistical value of Walt test also passed the significance test of 1%, indicating that the explanatory variables we designed have a significant impact on the environmental efficiency of cement manufacturing industry. In addition, in order to test whether there is a significant difference between the panel estimator and the mixed estimator, we test the likelihood ratio of *sigma_u*, the test *p* value shows that it is necessary to establish a panel data model.

After controlling for other factors, the regression results show that: (1)In various estimates, the coefficients of environmental regulation variables in the current period and lag 1 period are positive, and the coefficients of environmental regulation variables in the current period are statistically significant. This shows that during the study period, environmental regulation has a significant role in promoting environmental efficiency, and strict environmental regulation is conducive to the overall improvement of environmental efficiency of cement manufacturing industry; (2) From the hierarchical research results, R&D-M which reflects the ability of technological innovation, has passed the significance test of 1% level in all models; and it is another factor reflecting the ability of technological innovation The coefficients of R&D-P are all positive and statistically significant. The results show that there is a significant positive correlation between technological innovation and environmental efficiency, and improving the R&D investment of enterprises is another important way to promote the improvement of environmental efficiency of cement manufacturing industry; (3) In the control variables, the regression results of each column are relatively stable, and the coefficient and significance of control variables have no substantial change in the robustness test. The regression coefficients of energy consumption structure are significantly negative. The fundamental reason is that under the existing cement preparation process conditions, the unreasonable energy consumption structure that excessively depends on coal will inevitably increase pollutant emissions, resulting in poor environmental quality and low environmental efficiency. There is a significant positive correlation between the degree of industrialization and environmental efficiency, which indicates that improving the level of industrialization of cement manufacturing industry can not only increase economic output, but also have a positive impact on the control of pollution emissions, thus showing a significant role in promoting the improvement of environmental efficiency. Among all the influencing factors, the variable of economic scale has the largest and most significant effect on environmental efficiency. It may be that the larger the scale, the easier the cement enterprises to obtain the effect of scale economy. Through scale expansion, they can obtain more investment in pollution control and environmental technology, so as to promote the improvement of environmental efficiency. From the regression coefficient value, the negative impact of factor endowment structure on environmental efficiency is very small and not statistically significant. Changing the factor endowment structure in the short term has no substantial impact on the environmental efficiency of cement manufacturing industry.

Insert table 4 here

2.Regression analysis of regional panel data

According to the estimated results of Regional Panel Data in Table 5, there are significant regional differences in the impact of environmental regulation and technological innovation on environmental efficiency during the sample period: (1) The regression coefficients of current environmental regulation variables in model 1, 3 and 5 are 0.0421, 0.0913 and 0.1592, respectively, which are statistically significant. The regression coefficients of environmental regulation variables in lag 1 period are positive, and the coefficients of environmental regulation variables in central and western regions are statistically significant. This shows that environmental regulation has a significant positive impact on the environmental efficiency of cement manufacturing industry in the three regions, and has the greatest promotion effect on the environmental efficiency of cement manufacturing industry in the western region; (2) Except for the western region, the regression coefficients of R&D-M and R&D-P are significantly positive. Among them, the intensity of R&D personnel input in the eastern region and R&D funds input in the central region have the most significant impact on the environmental efficiency of cement manufacturing industry, which shows that technological innovation can indeed improve the environmental efficiency of cement manufacturing industry to a certain extent. However, due to various objective factors, it is difficult for the backward western regions to obtain the positive role of technological innovation in promoting environmental efficiency at least at present. From the regional perspective; (3) In the control variables, there are great differences between different regions. Energy consumption structure and factor endowment structure are negatively correlated with environmental efficiency in the central and western regions, while in the economically developed eastern regions, they have no significant impact on environmental efficiency. There is a significant positive correlation between the degree of industrialization and environmental efficiency in the eastern region, while the industrialization level has no substantial impact on environmental efficiency in the economically backward central and western regions. The size of the central region has the largest and most significant effect on environmental efficiency. However, in the economically backward western region, the expansion of economic scale is not conducive to the improvement of environmental efficiency of cement manufacturing industry.

Insert table 5 here

3.Robustness test

In order to enhance the reliability of research conclusions and avoid the estimation bias caused by single index measurement. Under the same conditions, ERI (2) is used to test the robustness of models 2, 4 and 6 in the above table. After repeating the above research steps, it is found that there is a significant positive correlation between environmental regulation, technological innovation and environmental efficiency, and the research conclusion remains unchanged.

5 Conclusion and policy recommendations

Based on the provincial panel data of cement manufacturing industry from 2004 to 2016, this paper empirically studies the impact of environmental regulation and technological innovation on the environmental efficiency of cement manufacturing industry by using Tobit regression model with limited dependent variables, and uses the sulfur dioxide emission rate as the proxy variable of environmental regulation to test the robustness. The results show that:

(1) Environmental regulation plays a significant role in improving the environmental efficiency of cement manufacturing industry. The design of environmental regulation policy to control pollution emission is an effective way to improve the environmental efficiency of cement manufacturing industry. Therefore, in the design of environmental regulation policy, the regulatory department should closely combine the pollution characteristics of cement manufacturing industry, and focus on monitoring the industrial (smoke) dust, sulfur dioxide, nitrogen oxides and other harmful emissions generated in the process of cement preparation. Secondly, while strictly controlling the emission standards, it will be a major innovative measure to play the guiding role of financial funds and drive social capital into the pollution control of cement enterprises to improve the environmental efficiency of cement manufacturing industry.

(2) There is a significant positive correlation between technological innovation and environmental efficiency of cement manufacturing industry, and technological innovation has become an important means to improve environmental efficiency. Existing statistics show that less than 2% of R&D investment intensity hinders the positive amplification effect of technological innovation on environmental efficiency, and also restricts the positive impact of R&D personnel investment on environmental efficiency. In view of this practical problem, on the one hand, we should continue to increase R&D investment in cement manufacturing industry, and timely introduce venture capital investment in the case of relatively insufficient self owned funds; On the other hand, to establish a new incentive mechanism and risk incentive mechanism for scientific and technological talents, we can improve the output efficiency of R&D personnel through equity option incentive, patent evaluation and other reform measures. Only by combining the two, can the positive amplification effect of technological innovation on environmental efficiency be highlighted.

(3) The national panel regression results show that the energy consumption structure has a significant negative correlation with the environmental efficiency of cement manufacturing industry, the level of industrialization has a significant positive effect on the environmental efficiency, while the factor endowment structure has no substantial impact on the environmental efficiency. Compared with other factors, the

scale factor has the greatest contribution to improve the environmental efficiency of cement manufacturing industry. Excessive dependence on coal and other primary energy causes the imbalance of energy consumption structure, which hinders the improvement of environmental efficiency of cement manufacturing industry. It can be seen that adhering to the strategy of "emission reduction first, energy saving as a supplement" is the future environmental regulation design direction of cement manufacturing industry. On the basis of mandatory emission reduction, continuously optimizing the energy consumption structure, improving the level of industrialization and industrial agglomeration are the realistic choices to realize the sustainable development of cement industry in the future.

(4) Regional panel regression results show that environmental regulation has a significant positive effect on the environmental efficiency of cement manufacturing industry in the three regions, and has the greatest impact on the environmental efficiency of cement manufacturing industry in the western region. Except for the western region, technological innovation plays a significant role in promoting the environmental efficiency of cement manufacturing industry in the eastern and central regions. According to the economic development of different regions, the implementation of differentiated control measures is more conducive to the healthy and sustainable development of cement industry. For the economically developed eastern region, we should strengthen environmental regulation, guide cement manufacturing enterprises to actively carry out technological innovation activities, reduce external environmental damage by encouraging the development of high-end cement products, and promote the continuous improvement of environmental efficiency; for the economically underdeveloped central and western regions, we should adopt steadily strengthened environmental regulation policies to force cement manufacturing enterprises to take the initiative to adjust Unreasonable energy consumption and factor endowment structure. In the process of undertaking industrial transfer, the cement manufacturing enterprises in the central and western regions should actively rely on the technical advantages of the eastern region, gradually improve their own industrialization level and industrial agglomeration degree, so as to obtain the long-term mechanism of environmental regulation on environmental efficiency.

Due to the influence of many subjective and objective factors, this research still has identified a number of limitations, which needs to be further explored in the follow-up research. Firstly, the current statistical data specifically for the cement manufacturing industry is not comprehensive and the quality is not high, so it is difficult to obtain the statistical data of enterprises below the scale. Secondly, although based on the existing research, this paper extends from the macroeconomic level to the mesoeconomic level, how to integrate the material flow analysis at the industrial technology level and the value flow analysis at the economic level, evaluate and analyze the micro effect will be an important research topic in the future. Thirdly, this paper only selects the sample data from 2004 to 2016, and the research conclusion only represents the basic situation of China's cement industry environmental efficiency during this period. It is also necessary to investigate the changes of cement industry environmental efficiency from a dynamic perspective according to China's economic development track, which will be the next direction worthy of research. Despite these limitations, this paper makes an important contribution to research on the environmental efficiency of China's cement manufacturing industry.

Data availability

Not applicable

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Contributions

All authors contributed to the study conception and design. Hongxing Tu gave the idea of this research work. Material preparation, data collection and analysis were performed by Wei Dai and Fengtao Hua.The first draft of the manuscript was written bu Hongxing Tu and Wei Dai. All authors read and approved the final manuscript.

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Ethics declarations

Ethics approval and consent to participate

Not applicable.

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Competing Interests

The authors declare no competing interests.

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Table 1

Variable definition

Variable type	Name	Symbol	Definition
dependent variable	Environmental efficiency	ETE	For the environmental efficiency score, see Formula 1
independent variable	Environmental regulation intensity	ERI(1)	For the removal rate of smoke (dust), see formula 2
		ERI(2)	For sulfur dioxide emission rate up to standard,See formula 3
	Technological innovation capability	R&D-M	The research and development expenditure of cement manufacturing industry accounts for the proportion of the total industrial output value.
		R&D-P	Investment intensity of R & D personnel, proportion of personnel engaged in scientific and technological activities in cement manufacturing industry.
	Energy consumption structure	EC	Proportion of coal consumption in total energy consumption of cement manufacturing industry
Control variable	Factor endowment structure	ES	Natural logarithm of capital labor ratio in cement manufacturing industry
	Degree of industrialization	DI	Per capita industrial added value of cement manufacturing industry
	Economic scale	Size	Natural logarithm of total assets of cement manufacturing industry
	Region	Region	Dummy variable (1 for eastern region, 0 for central and western region)
	year	Year	Dummy variable

Table 2
Descriptive statistics

Variable	Nationwide					Eastern Region				
	Mean	Standard Deviation	Maximum	Minimum	Observations	Mean	Standard Deviation	Maximum	Minimum	Observations
ETE	0.8884	0.143	1.00	0.524	390	0.9515	0.110	1.00	0.52	143
ERI(1)	87.354	9.319	99.920	61.330	390	92.712	5.984	99.92	70.17	143
ERI(2)	76.644	21.774	100	0.580	390	90.212	11.472	100	52.13	143
EC	85.544	8.317	99.600	30.369	390	83.08	9.785	98.03	30.37	143
ES	22.398	20.809	147.514	1.819	390	27.181	21.996	120.87	3.633	143
DI	11.549	9.889	45.903	0.873	390	13.625	10.983	45.903	1.744	143

Variable	Central region					Western Region				
	Mean	Standard Deviation	Maximum	Minimum	Observations	Mean	Standard Deviation	Maximum	Minimum	Observations
ETE	0.9013	0.133	1.00	0.538	104	0.8159	0.147	1.00	0.548	143
ERI(1)	84.761	9.66	98.92	64.70	104	83.882	9.403	98.70	61.33	143
ERI(2)	78.595	15.432	98.63	37.16	104	61.657	24.084	96.91	0.58	143
EC	85.129	7.169	99.306	64.014	104	88.309	6.522	99.60	47.82	143
ES	21.106	22.057	147.51	2.916	104	18.555	17.619	105.17	1.819	143
DI	11.073	9.538	37.563	1.40	104	9.819	8.588	33.061	0.873	143

Table 3

Correlation coefficient

Variable	*Pearson*	*Sig.* (2-tailed)	*Spearman*	*Sig.* (2-tailed)
ERI(1)	0.2269***	0.000	0.2197***	0.000
ERI(2)	0.3410***	0.000	0.3743***	0.000
R&D-M	0.1068***	0.000	0.1154***	0.000
R&D-P	0.1632**	0.015	0.1578**	0.018
EC	-0.1331**	0.044	-0.1122**	0.042
ES	-0.1421*	0.089	-0.1087*	0.091
DI	0.3181**	0.029	0.2985**	0.026
Size	0.2311***	0.000	0.2130***	0.000

Note: * Significant at 90% level

** Significant at 95% level

*** Significant at 99% level

Table 4

Tobit regression results of national panel data

Variable	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Constant term						
$\_Cons$	0.9965***	0.8163***	0.8480***	0.7220***	0.9584***	0.8289***
	（8.03）	（9.28）	（6.99）	（8.25）	（8.01）	（9.40）
Control variable						
$EC_{i,t-1}$	-0.0124*	-0.0906**	-0.0482*	-0.0182**	-0.0132**	-0.0102*
	（-1.78）	（-2.03）	（-1.67）	（-2.22）	（-2.48）	（-1.74）
$ES_{i,t-1}$	-0.0331	-0.0847	-0.0504	-0.0262	-0.0675	-0.0436
	（-0.63）	（-0.37）	（-0.89）	（-0.47）	（-1.22）	（-1.08）
$DI_{i,t-1}$	0.0485*	0.0384**	0.0475**	0.0391**	0.0290*	0.0208*
	（1.67）	（2.13）	（2.18）	（2.05）	（1.86）	（1.93）
$Size_{i,t-1}$	0.0687***	0.0892**	0.0589**	0.0511***	0.0435***	0.0364**
	（2.64）	（2.35）	（2.12）	（2.73）	（2.95）	（2.29）
Independent variable						
$ERI(1)_{i,t}$	0.0194**		0.0142*		0.0191*	
	（2.13）		（1.84）		（1.94）	
$ERI(1)_{i,t-1}$	0.0721		0.0516		0.0948	
	（1.32）		（1.20）		（1.42）	
$ERI(2)_{i,t}$		0.0198**		0.0208**		0.0207***
		（2.47）		（2.53）		（2.60）

$ERI(2)_{i,t-1}$		0.0914 （1.11）		0.0724 （1.09）		0.0955 （1.12）
$R\&D-M_{i,t-1}$	0.0512*** （2.72）	0.0514*** （2.81）			0.0417*** （2.86）	0.0332*** （2.91）
$R\&D-P_{i,t-1}$			0.0169** （2.52）	0.0176* （1.85）	0.0126* （1.90）	0.0118* （1.87）
$sigma\_u$	0.1001***	0.0987***	0.1026***	0.1012***	0.0997***	0.0983***
rho	0.8337	0.8039	0.8382	0.8127	0.8286	0.8011
*Wald chi*2	62.10***	78.90***	40.16***	55.42***	66.28***	83.12***
Log Likelihood	308.26	315.29	298.55	305.32	310.06	317.03
OBS	390	390	390	390	390	390

Note: The values in brackets represent Z statistics. *sigma_u* represents the standard deviation of individual effects, *rho* indicates the proportion of individual effect fluctuation in the overall fluctuation. *OBS* represents the number of sample observations.

* Significant at 90% level

** Significant at 95% level

*** Significant at 99% level

Table 5
Tobit regression results of regional panel data

Variable	Eastern average		Central average		Western average	
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Constant term						
$\_Cons$	1.2266*** （6.76）	1.1288*** （8.84）	0.9689*** （5.11）	0.7019*** （4.43）	1.1211*** （5.23）	0.9160*** （5.05）
Control variable						
$EC_{i,t-1}$	-0.0296 （-0.32）	-0.0132 （-0.14）	-0.0162** （-2.06）	-0.0142* （-1.76）	-0.1229*** （-2.73）	-0.1016** （-2.16）
$ES_{i,t-1}$	-0.0185 （-0.26）	-0.0117 （-0.17）	-0.0630* （-1.79）	-0.0482* （-1.83）	-0.2803** （-2.27）	-0.2159** （-2.05）
$DI_{i,t-1}$	0.0242* （1.85）	0.0154** （2.13）	0.0940 （1.52）	0.0691 （1.29）	0.0192 （1.57）	0.0123 （1.44）
$Size_{i,t-1}$	0.0174 （0.93）	0.0191 （1.06）	0.0877** （2.51）	0.0969*** （2.89）	-0.0104 （-0.36）	-0.0167 （-0.48）
Independent variable						
$ERI(1)_{i,t}$	0.0421** （2.13）		0.0913* （1.87）		0.1592** （2.20）	
$ERI(1)_{i,t-1}$	0.0313 （1.45）		0.0490* （1.75）		0.1149* （1.94）	
$ERI(2)_{i,t}$		0.0643* （1.79）		0.0146** （2.07）		0.1367** （2.26）

$ERI(2)_{i,t-1}$		0.0264* （1.67）		0.0253* （1.72）		0.0188* （1.83）
$R\&D-M_{i,t-1}$	0.0289* （1.69）	0.0302* （1.71）	0.1504*** （3.41）	0.1894*** （3.35）	0.0441 （1.27）	0.0641 （1.33）
$R\&D-P_{i,t-1}$	0.0248** （2.11）	0.0265** （2.22）	0.0799* （1.82）	0.1156** （2.24）	0.0425 （0.93）	0.0475 （1.01）
sigma_u	0.0871***	0.0895***	0.0966**	0.1076**	0.1116***	0.1089
rho	0.6210	0.6231	0.7159	0.7393	0.7544	0.7432
Wald chi2	58.77**	55.36**	62.51***	56.80***	46.44***	51.53***
Log Likelihood	164.38	161.08	92.72	89.88	101.31	102.83
OBS	143	143	104	104	143	143

Note: The values in brackets represent Z statistics. *sigma_u* represents the standard deviation of individual effects, *rho* indicates the proportion of individual effect fluctuation in the overall fluctuation. *OBS* represents the number of sample observations.

* Significant at 90% level

** Significant at 95% level

*** Significant at 99% leve