Pol. J. Environ. Stud. Vol. 31, No. 3 (2022), 2157-2166
DOI: *10.15244/pjoes/143919* ONLINE PUBLICATION DATE: 2022-02-28

Original Research

Environmental Regulation, Industrial Structure Upgrading and Technological Innovation: Empirical Data from Guangdong Province in China

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Received: 12 May 2021
Accepted: 13 November 2021

Abstract

Environmental regulation has obvious externality on technological innovation. How to protect the environment without exerting negative effects on technological innovation activities carried out by enterprises is an important realistic proposition in economic development. Taking the panel data of 21 cities in Guangdong Province from 2005 to 2018 as the research object, the paper empirically studies the impact of environmental regulation on technological innovation, as well as the moderating effect and threshold effect of the industrial structure upgrading on the relationship between them. The results show that there is an inverted U-shaped effect of environmental regulation on technological innovation, and a moderate intensity of environmental regulation is conducive to promoting the development of technological innovation. The industrial structure upgrading plays a significant negative moderating effect in the inverted U-shaped relationship on the whole, causing the curve of the inverted U-shaped relationship to move to the left. Furthermore, through the threshold regression model, we find that the moderating effect of industrial structure upgrading has significant nonlinear characteristics. The level of upgrading lower than the first threshold or higher than the second threshold is not conducive to the effect of environmental regulation on technological innovation. In the implementation process of environmental regulation, more attention should be paid to promoting the rationalization of industrial structure in combination with industrial policies.

Keywords: environmental regulation; technological innovation; industrial structure upgrading

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Introduction

Environmental regulation refers to the governmental control and intervention on the production and operation activities of enterprises to solve environmental problems, including the formulation and the implementation of a series of laws, policies, protection measures and codes of conduct [1]. With the development of economy and society, environmental pollution has emerged as a matter with great concern and increasing severity, so it is urgent to foster environmental protection. Both environmental protection and innovation-driven development have become China's two major national strategies. How to protect the environment without affecting technological innovation activities of enterprises is an important practical proposition for Chinese economic and social development. To achieve the balance between environmental regulation and technological innovation, a deeper understanding of their relationship is required. In fact, the research on the impact of environmental regulation on technological innovation and enterprise competitiveness started relatively early. Neoclassicism believed that environmental regulation had an inhibitory effect on technological innovation. In 1991, Porter and van der Linde challenged the theoretical framework of Neoclassicism and proposed that environmental regulation and enterprise competitiveness could be mutually beneficial and reach a win-win situation. In other words, moderately stringent environmental regulation could ultimately promote technological innovation activities and productivity of enterprises, thus offsetting the costs brought by environmental protection and rendering enterprises competitive advantages [2]. After that, many scholars tested the Porter Hypothesis and further proposed various hypotheses like the Strong Porter Hypothesis, Weak Porter Hypothesis and Narrow Porter Hypothesis with different empirical results. The Porter Hypothesis supporters believed that environmental regulation gave enterprises an incentive to promote technological innovation in the long run [3-6], while the opponents empirically proved the invalidity of the Porter hypothesis and concluded that environmental regulation inhibited technological innovation [7-10]. Furthermore, the impact of environmental regulation on technological innovation was also described as an inverted N-shaped, U-shaped, inverted U-shaped in some studies [11-16]. For the relationship between them, scholars all over the world have not reached a consensus. A possible reason for such disagreement is that there are various factors relating to the impact of environmental regulation on technological innovation, such as the level of local economic development, industrial structure, regional R&D investment, and the degree of opening up to the outside world [17-19]. Since different regions were chosen as research objects, and there was more than one research period as well as variable selection method even in the same region, research conclusions drawn from distinct studies varied. Therefore, to get an accurate research conclusion on how environmental regulation affects technological innovation in a specific region, the empirical analysis based on the data indicators of a certain period in this region is required. Based on this, this study empirically tests the impact of environmental regulation on technological innovation by taking the relevant data of 21 cities in Guangdong, China from 2005 to 2018 as research objects. At the same time, taking the moderating effect of industrial structure upgrading into account, this paper also analyzes how industrial structure upgrading influences the effect of environmental regulation on technological innovation so as to provide countermeasures and suggestions corresponding to the local industrial structure state of a region.

Theoretical Analysis and Research Hypothesis

The impact of environmental regulation on technological innovation is inevitably affected by various factors in a specific region, like the level of its economic development, industrial structure, and foreign investment. Therefore, it is necessary to analyze the differentiated impact brought by different factors. Based on the above literature review and analysis, this paper puts forward the following two hypotheses.

Hypothesis 1: Environmental regulation has an inverted U-shaped effect on technological innovation.

The relationship between environmental regulation and technological innovation was depicted as linear effect, U-shaped effect, inverted U-shaped effect, and N-shaped effect in previous literature review. According to statistical data, the technological innovation capacity of cities in Guangdong Province has been greatly improved in the past few years, while the intensity of environmental regulation has not been significantly enhanced or reduced simultaneously. It seems that there is no synchronous linear relationship between environmental regulation and technological innovation. At the same time, environmental regulation has both positive "compensation effect" and negative "offset effect" on technological innovation [12], and the relationship between them is more likely to be nonlinear. Therefore, the paper assumes that there is an inverted U-shaped impact of environmental regulation on technological innovation. The accurate relationship depends on the coefficients of environmental regulation and its quadratic term in our model and further analysis is conducted based on the empirical results.

Hypothesis 2: Industrial structure upgrading has a negative moderating effect on the relationship between environmental regulation and technological innovation. The excessive upgrading of industrial structure is not conducive to the effect of environmental regulation on technological innovation.

With the upgrading of an industrial structure, the proportion of the primary industry decreases, while that of the secondary industry and the tertiary industry gradually increases and the tertiary industry becomes the leading one in the late stage of the upgrading. Under the law of industry development, in the initial stage of industrial structure transformation and upgrading, the secondary industry grows rapidly and gradually develops into the leader. The manufacturing industry becomes the dominant industry at this stage and upgrading of the industrial structure can prominently enhance the regional technological innovation capacity. With the further upgrading of the industrial structure, the output value of the tertiary industry exceeds that of the secondary industry, and gradually dominates the industrial structure. In this case, there are two types of industrial structures. One is that output values of the secondary and tertiary industries are increasing, but the growth rate of the tertiary industry is faster. The other is that the industrial structure realizes fully service-oriented transformation with proportions of the primary and secondary industries gradually decreasing, forming a "virtual upgrading" industrial structure. The scale of the secondary industry reduces, probably leading to the overall decline of regional technological innovation capacity, which means that the service-oriented transformation of an industrial structure does not accelerate technological innovation. In addition, environmental regulation imposes strict restrictions on industries with high pollution and high energy consumption, and technology-and-knowledge-intensive industries with low pollution and low energy consumption obtain more governmental support. In the process of industrial upgrading, the continuous improvement of energy saving and emission reduction technologies weakens the "cost effect" of environmental regulation for enterprises, which may undermine enterprises' motivation for technological innovation under the same environmental regulation intensity. Therefore, the upgrading of industrial structure may inhibit the effect of environmental regulation on technological innovation. Based on the above analysis, the paper assumes that in the case of excessive upgrading of industrial structure, environmental regulation may in turn inhibit technological innovation. We then make further exploration and analysis according to the empirical results.

Material and Methods

Model Setting

Basic Model

In order to verify the inverted U-shaped relationship between environmental regulation and technological innovation, the quadratic term of explanatory variable is added into the model according to the analysis method of Environmental Kuznets curve applied to analyze environmental pollution and economic growth. Meanwhile, considering that the technological innovation level of a certain period may be affected by that of the former period, the lag term of the explained variable is introduced as the explanatory variable to establish a dynamic regression model:

$$\ln(TI)_{i,t} = \alpha_0 + \alpha_1 \ln(TI)_{i,t-1} + \alpha_2 ER_{i,t} + \alpha_3 ER_{i,t}^2 + \beta_1 X_{i,t} + \theta_t + \delta_i + \varepsilon_{i,t} \quad (1)$$

In the model (1), i, t, TI, ER, ER^2 and X respectively represent city, year, technological innovation level, environmental regulation, the quadratic term of environmental regulation and other control variables such as the GDP per capita, FDI, and R&D investment. θ_t and δ_i are time effect and individual effect respectively, and ε is the error term.

Moderating Effect Model

In order to verify whether industrial structure upgrading plays a moderating role in the impact of environmental regulation on technological innovation, the interaction term between industrial structure upgrading and environmental regulation is added on the basis of model (1):

$$\ln(TI)_{i,t} = \alpha_0 + \alpha_1 \ln(TI)_{i,t-1} + \alpha_2 ER_{i,t} + \alpha_3 ER_{i,t}^2 + \alpha_4 ER_{i,t} \times IS_{i,t} + \beta_1 X_{i,t} + \theta_t + \delta_i + \varepsilon_{i,t} \quad (2)$$

In model (2), IS refers to the variable of industrial structure upgrading and $ER \times IS$ is the interaction item between industrial structure upgrading and environmental regulation.

Threshold Effect Model

In order to further explore the nonlinear relationship among environmental regulation, industrial structure upgrading and technological innovation and describe the moderating effect of industrial structure upgrading, a panel threshold model (3) is established with industrial structure upgrading as the threshold variable:

$$\ln(TI_{i,t}) = \alpha_0 + \alpha_1 ER_{i,t} \cdot I(IS_{i,t} \le \lambda) + \alpha_2 ER_{i,t} \cdot I(IS_{i,t} > \lambda) + \beta_1 X_{i,t} + \theta_t + \delta_i + \varepsilon_{i,t} \quad (3)$$

In model (3), λ is an unknown threshold value, and $I(\cdot)$ is the indicator function. When the conditions in parentheses are met, its value is 1, otherwise it is 0.

Variable Selection and Description

Explained Variable

The explained variable of this paper is technological innovation (TI). At present, patent indicators are widely used to measure technological innovation output in academia [20-22]. Therefore, this paper uses the amount of invention patent authorization as an index of technological innovation. In addition, in order to narrow down the range of variables and facilitate the interpretation of regression coefficients, the logarithm treatment is adopted for variables.

Core Explanatory Variables

Environmental regulation: At present, the quantitative measurement of environmental regulation intensity is still a difficulty of study, and there is no universally accepted measurement method. Some literatures indirectly reflected the intensity of environmental regulation by using the emissions of various pollutants [23-25]. This method is easily disturbed by abnormal climate change, resulting in the deviation of selected indicators. A comprehensive index was built to measure the pollution control effect in some studies, using various environmental management indicators like industrial wastewater discharge standard rate, industrial sulfur dioxide removal rate, industrial smoke (dust) removal rate and comprehensive utilization rate of industrial solid waste [26-28]. Pollution control investment expenditure was also used for measurement. For example, Zhou et al. [25] and Rubashkina et al. [29] used pollution control expenditure to measure environmental regulation stringency. In addition, some literatures measure the intensity of environmental regulation by using the number of regulatory authorities' inspections on enterprise pollution [30]. But these methods are all indirect measurements, failing to fully reflect environmental regulation intensity. In order to overcome such shortcomings of the above measurement methods, this paper applies the frequency of environmental protection words in work reports of local governments as a proxy variable to measure environmental regulation based on the method proposed by Chen et al. [31]. This method can more directly and accurately reflect the extent of the importance that governments attach to the environmental regulation. Specifically, the method uses the proportion of statements containing words or phrases related to environmental regulation (e.g. environment, energy consumption, pollution, emission reduction, environmental protection) in annual work reports of the municipal governments as the measurement standard.

Industrial structure upgrading: In the exploration of the evolution law of industrial structure, measurement indexes were studied to represent industrial structure optimization and upgrading. Proportions of the three industries were used as such a measurement index [32, 33]. Based on the research of Li et al. [34], this paper adopts the proportion of the added value of the tertiary industry in GDP to measure the industrial structure upgrading.

Control Variables

In order to control the interference introduced by regional characteristics to technological innovation, this paper selects the foreign direct investment (FDI), per capita GDP (PGDP), proportion of regional R&D investment in GDP (RD) as control variables which can be measured by mature data indicators. Specifically, the paper selects the whole society R&D investment as the proxy index of regional R&D investment. The variables of PGDP and FDI are obtained from the statistical data published by each city, and are logarithmically processed.

Data Collection and Descriptive Statistics

The research objects of this paper are 21 cities in Guangdong, including Guangzhou, Shenzhen, Zhuhai, Foshan, Jiangmen, Dongguan, Zhongshan, Huizhou, Zhaoqing, Shantou, Shanwei, Chaozhou, Jieyang, Zhanjiang, Maoming, Yangjiang, Shaoguan, Heyuan, Meizhou, Qingyuan and Yunfu, and the time range of the data sampled is from 2005 to 2018. Additionally, this paper collects the work reports of municipal governments in Guangdong as the data source of environmental regulation indicator, and locates relevant sentences with keywords including environment, energy consumption, pollution, emission reduction and environmental protection. The frequency of these words related to environmental protection is calculated to measure the intensity of environmental regulation. The amount of invention patent authorization in each city comes from the patent statistics issued by Guangdong Intellectual Property Office, and other data

Table 1. Descriptive statistics of relevant index data.

Variable	Mean	Standard Deviation	Min	Max
TI	1001.568	2906.420	1.000	21310.000
ER	0.057	0.021	0.009	0.138
IS	0.420	0.078	0.275	0.718
PGDP	46776.687	38163.726	7417.000	203225.000
RD	1.060	0.943	0.010	4.800
FDI	142398.333	409214.561	1680.000	5145641.000

come from Guangdong statistical yearbooks. Table 1 demonstrates the descriptive statistical results of each variable.

Relationship Between Environmental Regulation and Technological Innovation

This paper uses the panel data of 21 cities in Guangdong Province from 2005 to 2018. Since model (1) and (2) are dynamic panel models with the lag term of the explained variable added to the explanatory variables, classical OLS methods such as mixed OLS, random effect model and fixed effect model may lead to biased regression estimation results. Therefore, this paper adopts the difference GMM method and uses the lag terms of the variable as the instrumental variables to alleviate the endogenous problem of dynamic panel model. Table 2 shows the regression results of model (1) using methods of mixed OLS, random effect model, fixed effect model and difference GMM.

The regression coefficients and significance obtained by the four estimation methods are quite similar. According to the estimative results of the difference GMM in Table 2, there is a significantly inverted U-shaped relationship between environmental regulation and technological innovation. The coefficients of environmental regulation (*ER*) and its quadratic term (ER^2) are 25.184 and -201.932 respectively, which are all significant at the level of 1%, indicating that when environmental regulation is less stringent, increasing the intensity of environmental regulation will significantly promote the level of technological innovation. When the intensity of environmental regulation exceeds the inflection point, strengthening environmental regulation will in turn inhibit the improvement of technological innovation. In addition, the coefficient of the lag term is significantly positive at the level of 1%, which indicates that there is a certain degree of path dependence for the technological innovation in Guangdong, and the correlation between adjacent periods is positive. Among the control variables, the GDP per capita and R&D investment exert a significantly positive impact on the level of technological innovation, which is in line with expectations. The coefficient of GDP per capita is 0.937, indicating that for every 1% increase in GDP per capita, the level of technological innovation will increase by 0.937% on average. A solid economic foundation can strongly support the development of technological innovation activities, and the improvement of economic level will help to promote the regional innovation capability. The coefficient of regional R&D investment is 0.209, indicating that for every 1% increase in the proportion of R&D investment in GDP, the level of technological innovation will increase by 0.209% on average, and increasing R&D investment will significantly improve the innovation output. The coefficient of FDI is also positive, but it does not pass the significance test. A possible reason is that Guangdong's advantage of backwardness in technological innovation has gradually disappeared at this stage, and it is difficult to quickly improve

Table 2. Regression results of the relationship between environmental regulation and technological innovation.

	(1)	(2)	(3)	(4)
	Mixed OLS	Random Effect Model	Fixed Effect Model	Difference GMM
$\ln(TI)_{t-1}$	——	——	——	0.589^{***} (25.67)
ER_t	28.222^{***} (2.76)	22.774^{***} (3.43)	22.632^{***} (3.39)	25.184^{***} (3.11)
ER_t^2	-229.961^{***} (-3.02)	-207.290^{***} (-4.17)	-207.362^{***} (-4.15)	-201.932^{***} (-3.24)
$\ln(PGDP)_t$	1.508^{***} (11.10)	1.802^{***} (17.61)	1.817^{***} (17.55)	0.937^{***} (7.29)
RD_t	0.813^{***} (7.70)	0.872^{***} (9.21)	$0. 883^{***}$ (9.05)	0.209^{*} (1.65)
$\ln(FDI)_t$	0.072 (1.37)	-0.051 (-0.97)	-0.055 (-0.98)	0.023 (0.57)
constant	-13.606^{***} (-10.98)	-15.216^{***} (-14.49)	-15.334^{***} (-14.30)	——
AR(1)	——	——	——	[0.001]
AR(2)	——	——	——	[0.192]
Sargan-test	——	——	——	[0.302]

Note: The values in () are test statistics, and the values in [] are test probability. *, ** and *** are significant at the levels of 10%, 5%, and 1%, respectively.

its technological innovation ability through the introduction of foreign direct investment. It may also because of multinational corporations' control over core technologies through measures such as "black box" of key technologies, which makes it difficult for domestic companies to imitate and innovate based on foreign advanced technologies brought by foreign investment.

In the application of the difference GMM method, the validity of the empirical results needs testing by using the serial correlation test and the over-identification test of instrumental variables. In the last three rows of Table 2, the p-values of AR (1) and AR (2) are 0.001 and 0.192 respectively, indicating that there is only first-order autocorrelation but no second-order autocorrelation in the residuals. The p-value of sargan test is 0.302, greater than 10%, which fails to pass the significance test, indicating that there is no over-identification problem in the instrumental variables. The results prove the validity of the difference GMM estimation.

Moderating Effect of Industrial Structure Upgrading

Table 3 shows the regression results of model (2) using methods of the mixed OLS, random effect model, fixed effect model and difference GMM. From the results of the last column in Table 3, there is still a significantly inverted U-shaped relationship between environmental regulation and technological innovation, and the estimated coefficient symbols of control variables are the same as those in model (1). The coefficient of industrial structure upgrading is 9.492 and significant at 10% level, which shows that for every unit of industrial structure upgrading, the technological innovation capability will increase by about 9.5% on average. Industrial transformation and upgrading can optimize the allocation of R&D resources and promote R&D efficiency, thus improving the overall technological innovation capability. The coefficient of the interaction term between industrial structure upgrading and environmental regulation is -91.952 and significant at the level of 5%. The results show that industrial structure upgrading has a negative moderating effect on the relationship between environmental regulation and technological innovation. With the upgrading of industrial structure, the peak (inflection point) of the inverted U-shaped curve reflecting the relationship between environmental regulation and technological innovation moves to the left, indicating that industrial structure upgrading will weaken the effect of environmental regulation on technological innovation. For a certain intensity of environmental regulation, the upgrading of industrial structure may change its positive effect on technological innovation into inhibition. A possible reason is that the upgrading

Table 3. Regression results of the moderating effect of industrial structure upgrading.

	(1)	(2)	(3)	(4)
	Mixed OLS	Random Effect Model	Fixed Effect Model	Difference GMM
$\ln(TI)_{t-1}$	——	——	——	0.400^{***} (4.95)
ER_t	52.756^{***} (2.95)	31.899^{***} (2.84)	31.076^{***} (2.75)	71.591^{***} (2.80)
ER_t^2	-237.450^{***} (-3.36)	-200.641^{***} (-4.36)	-199.509^{***} (-4.31)	-263.302^{***} (-3.19)
IS_t	8.616^{***} (3.81)	7.526^{***} (4.70)	7.546^{***} (4.62)	9.492^{**} (2.46)
$ER_t \times IS_t$	- 54.168 (-1.52)	-20.131 (-0.90)	-18.723 (-0.84)	-91.652^{**} (-1.99)
$\ln(PGDP)_t$	1.191^{***} (8.88)	1.385^{***} (12.35)	1.390^{***} (12.07)	1.055^{***} (7.43)
RD_t	0.804^{***} (8.18)	0.829^{***} (9.39)	0.835^{***} (9.17)	0.244^{*} (1.83)
$\ln(FDI)_t$	0 .049 (1.01)	-0.031 (-0.64)	-0.031 (-0.60)	0.008 (0.20)
constant	-13.727^{***} (-10.15)	-14.232^{***} (-13.19)	-14.297^{***} (-12.99)	——
AR(1)	——	——	——	[0.002]
AR(2)	——	——	——	[0.178]
Sargan-test	——	——	——	[0.107]

Note: The values in () are test statistics, and the values in [] are test probability. *, ** and *** are significant at the levels of 10%, 5%, and 1%, respectively.

of industrial structure will reduce the sensitivity of industrial subjects (enterprises) to environmental regulation, and enterprises are less likely to carry out new technological innovation activities for pollution control. In addition, the industrial structure upgrading has promoted the development of clean energy technology, which reduces the cost of enterprises' compliance with environmental regulation and weakens their enthusiasm for technological innovation as well as the "innovation compensation effect".

Robustness Test

The paper adopts the method of replacing the explained variable to test the robustness of the empirical results. The amount of invention patent authorization is replaced with the output value of new products and the sales revenue of new products as the proxy variables of technological innovation. The regression results of the models are obtained again, as shown in Table 4. The results of the difference GMM estimation demonstrate that no matter which proxy variable is in use, there is a significant inverted U-shaped relationship between environmental regulation and technological innovation. The coefficient of the interaction term between industrial structure upgrading and environmental regulation is significantly negative, and the coefficients of control variables are also consistent with those in the previous models, indicating that the empirical results of this paper have strong robustness.

Threshold Effect Test

The above theoretical analysis has shown that there seems to be a nonlinear moderating effect of industrial structure upgrading on the relationship between environmental regulation and technological innovation. In order to further explore the specific characteristics of the moderating effect, the paper constructs the threshold effect model with industrial structure upgrading as the threshold variable. The results of the significance test of threshold effect in Table 5 show that the single threshold test and double threshold test have passed the significance test at the level of 1% and 5% respectively, indicating that there is a double threshold effect in the moderating role of industrial structure upgrading, and the threshold values are 0.4693 and 0.5489 respectively.

From the regression results of threshold model in Table 6, it can be seen that the impact of industrial structure upgrading on the relationship between environmental regulation and technological innovation shows significantly nonlinear characteristics. When the degree of industrial structure upgrading is lower than 0.4693, the coefficient of environmental regulation is -3.682, indicating that environmental regulation significantly inhibits the development of technological innovation. At this stage, the level of industrial structure upgrading is relatively low, and the "innovation compensation effect" of enterprises stimulated by environmental regulation is not enough to make up for the "cost effect". In order not to affect normal operations, enterprises often choose to reduce innovation investment, which hinders the progress of regional technological innovation. When the degree of industrial structure upgrading crosses the first threshold and is between 0.4693 and 0.5489, the coefficient becomes 8.400, indicating that environmental regulation can significantly improve the level of technological innovation. With the further upgrading

Table 4. Robustness test resuls.

	Output value of new products		Sales revenue of new products	
	(1)	(2)	(3)	(4)
$\ln(TI_{t-1})$	0.711*** (7.20)	0.601*** (7.58)	0.734*** (7.46)	0.631*** (7.58)
ER_t	40.912** (2.47)	86.490*** (2.66)	40.303** (2.41)	86.184*** (2.74)
ER_t^2	-333.552** (-2.46)	-311.443** (-2.52)	-335.775** (-2.47)	-326.627*** (-2.60)
IS_t	——	11.403** (2.14)	——	10.644** (2.09)
$ER_t \times IS_t$	——	-113.112* (-1.79)	——	-109.826* (-1.78)
Control variables	Yes	Yes	Yes	Yes
AR(1)	[0.004]	[0.003]	[0.008]	[0.006]
AR(2)	[0.225]	[0.191]	[0.244]	[0.215]
Sargan-test	[0.245]	[0.394]	[0.538]	[0.700]

Note: The values in () are test statistics, and the values in [] are test probability. *, ** and *** are significant at the levels of 10%, 5%, and 1%, respectively.

Table 5. Results of the significance test of threshold effect.

Threshold variable	Threshold model	F-statistic	p-value	Threshold value	95% confidence interval
IS	Single threshold	39.89	0.0000	0.4693***	[0.4636, 0.4700]
	Double threshold	18.23	0.0300	0.5489**	[0.5388, 0.5551]
	Triple threshold	14.00	0.4540	0.4170	[0.4136, 0.4171]

Note: *, ** and *** are significant at the levels of 10%, 5%, and 1%, respectively.

Table 6. Regression results of the threshold effect model.

Variable	Coefficient	t-statistic	p-value	95% confidence interval
ER_t ($IS_t \leq 0.4693$)	-3.682**	-2.13	0.034	[-7.088, -0.276]
ER_t ($0.4693 < IS_t \leq 0.5489$)	8.400***	3.50	0.001	[3.680, 13.120]
ER_t ($IS_t \geq 0.5489$)	-8.394**	-2.02	0.044	[-16.555, -0.232]
$\ln(PGDP)_t$	1.608***	15.96	0.000	[1.410, 1.806]
RD_t	0.926***	9.73	0.000	[0.738, 1.113]
$\ln(FDI)_t$	0.024	0.47	0.639	[-0.078, 0.127]
Constant	-13.376***	-13.04	0.000	[-15.396, -11.355]

Note: *, ** and *** are significant at the levels of 10%, 5%, and 1%, respectively.

of industrial structure, enterprises have established a more solid R&D foundation, and environmental regulation can stimulate sufficient "innovation compensation effect" to promote technological transformation and innovation. When the industrial structure upgrading is higher than the second threshold value of 0.5489, the coefficient is -8.394. Environmental regulation has a stronger inhibitory effect on technological innovation than the first stage, which confirms the Hypothesis 2 that the excessive upgrading of industrial structure is not conducive for environmental regulation to promote technological innovation. The threshold regression results of the three stages show that industrial structure upgrading with too low or too high degree will lead to the inhibitory effect of environmental regulation on technological innovation. Only when the industrial structure upgrading is in a reasonable development stage, environmental regulation can play a positive role on regional innovation.

Conclusions

Due to the unclear externality of environmental regulation on enterprise innovation under different conditions, it is necessary to study the influential mechanism of environmental regulation on technological innovation. Using the panel data of 21 cities in Guangdong Province from 2005 to 2018, this paper constructs a moderating effect model and a threshold effect model to explore the relationship between environmental regulation and technological innovation, and the moderating role of industrial structure upgrading. The main conclusions are as follows:

(1) Environmental regulation has an obvious inverted U-shaped impact on technological innovation. With the increasing intensity of environmental regulation, the effect on technological innovation has gradually changed from promotion to inhibition. When the intensity of environmental regulation is weak, strengthening environmental regulation will significantly promote the level of technological innovation. When the intensity of environmental regulation crosses the inflection point, excessive environmental regulation will in turn inhibit technological innovation. Therefore, in the process of environmental protection and supervision, local governments should reasonably control the intensity of environmental regulation, formulate appropriate policies in combination with the current situation, strengthen the construction of local laws and regulations on environmental protection, and establish a diversified and multi-level environmental protection system, so as to improve the effectiveness of environmental regulation and promote the high-quality development of technological innovation.

(2) Industrial structure upgrading plays a negative moderating role in the relationship between environmental regulation and technological innovation on the whole. From 2005 to 2018, the scale of the secondary industry dominated by manufacturing in Guangdong Province expanded continually, and a considerable number of the manufacturing

enterprises caused serious pollution to the environment in the production process. With the expansion of the number and scale of these enterprises, they are more sensitive to environmental regulation, and it is easier for the enhancement of environmental regulation intensity to break through the inflection point and exert an inhibitory effect on technological innovation. Furthermore, the results of panel threshold model show that the moderating effect of industrial structure upgrading is nonlinear. Industrial structure upgrading with too low or too high degree will lead to the inhibitory effect of environmental regulation on technological innovation. Only when the industrial structure upgrading is in a specific development stage, environmental regulation is more likely to promote technological innovation. Therefore, local governments should reasonably adjust the intensity of environmental regulation according to the characteristics of local industrial structure. At the same time, policies and measures should be taken to optimize the resource allocation and fiscal expenditure in different industries, thus promoting the rationalization of industrial structure. Finally, relevant government departments should not only try to promote the transformation and upgrading of industrial structure, but also prevent the severe decline of the proportion of secondary industry especially manufacturing industry, and avoid the over-servitization of industrial structure.

Acknowledgments

This research was funded by Soft Science Research Project of Guangdong Province (2018B070714013, 2016B070702002).

Conflict of Interest

The authors declare no conflict of interest.

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