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Dynamic Relationship Between Technology Innovation of Industrial Enterprises and Environmental Pollution: A Case Study of Zhejiang Province, China

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ABSTRACT

Industrial enterprises are rising in China, but their backward technological level, poor independent innovation capability, excess production capacity, and low utilization efficiency of resources and energy have resulted in serious environmental pollution. The overall technology innovation efficiency of industrial enterprises in China can be effectively improved to reduce the industrial "three-waste" discharge but only when the enterprises promote structural optimization and adjust themselves toward industrial services through technology innovation. The influence of R&D expenditures of large- and medium-sized industrial enterprises on industrial "three-waste" discharge was estimated based on the panel data of 11 prefecture-level cities in Zhejiang Province during 2005-2016. In addition, technology innovation measures for environmental pollution control of industrial enterprises were proposed. The results demonstrated that enterprise technology innovation has an environmental protection effect, and improved enterprise production efficiency contributes to the reduction of pollutant discharge. Besides, enterprise R&D expenditures in most cities in Zhejiang Province are negatively correlated with environmental pollutant discharge, and the influence is significant. Moreover, the technology innovation input of industrial enterprises can reduce industrial pollutant discharge in Hangzhou, Ningbo, Wenzhou, Huzhou, and Taizhou due to their good economic foundations. The study results in this paper have a direct and realistic significance in analysing the influence mechanism for the technology innovation of ecological environmental pollution of enterprises, promoting optimization and upgrading of industrial structures in different regions, and elevating regional environmental pollution governance level.

INTRODUCTION

In recent years, China has gained impressive achievements in promoting urbanization and industrialization. However, the country has since suffered from resource overuse and "governance after pollution" at the price of ecological environment due to the one-sided pursuit of rapid economic growth even if improvement of economic quality is neglected, thereby increasing the cost and difficulty of environmental governance in China. Moreover, China's industry has consistently been in a large but not strong development phase with a backward overall technology level and poor independent innovation capability, serious excess production capacity and great difficulty in eliminating backward production capacity low utilization efficiency of resources and energies and enormous challenges in energy conservation and emission reduction, continuously declining profits in the manufacturing industry, consistently being a low value-added and medium and low-end link in the international value chain, and the fast rise of labour wages and rapid loss of comparative advantages. Owing to a gradual recession and missed of demographic dividends, the "low-cost advantage" of "Made in China" has been gradually declining, and it faces a new round of effects from global technology and the industrial revolution. Moreover, in consideration of seriously insufficient late-mover advantages and innovation input of the manufacturing industry, China's industrial enterprises are in urgent need of technology innovation. Rapid industrial development is the main source of a series of environmental problems, such as the energy, ecological, and climate change crises in China, and environmental technology innovation is the key to solving these problems. However, environmental technology innovation is an externality and will result in an increase in additional costs to enterprises. Thus, enterprises themselves lack internal impetus to strive for environmental technology innovation. Enterprises will consider developing and adopting technologies related to environmental protection and resource saving only when motivated by external factors, like environmental policies. Zhejiang Province is a province with a developed economy. As shown in Fig. 1, industrial output value presents a year-by-year growth tendency but results in serious environmental pollution. The environment in Zhejiang Province suffers from severe destruction and pollution with concentrated reflection and explosion of ecological and environmental problems within a short term. Thus, environmental pollution governance is an urgent concern. Solving long-term environmental problems only by depending on increased investment for environmental pollution governance is insufficient. Technology innovation of industrial enterprises can not only reduce pollutant discharge by advanced production technologies and techniques but can also improve end-treatment efficiency. Meanwhile, innovation can use high technologies to develop high-tech industries and reduce excess consumption and utilization of energies to reduce environmental pollutants generated by energy consumption. Technology innovation is a key link in governing environmental pollution and improving environmental quality and the technology effect plays a significant role in the improvement of environmental quality. The fundamental impetus of enterprise development is innovation, which is an inevitable choice for enterprises to adapt to sustainable social development and satisfy their own sustainable development. Technology innovation can save energy sources and reduce energy consumption so that waste can be recycled and reused, which can not only improve energy utilization efficiency, but also can effectively relieve or offset the increase of enterprise production cost caused by constraints of environmental policies and improve product competitiveness.

PAST STUDIES

Foreign developed countries have conducted many studies on the relationship between technology innovation and environmental pollution control, and many achievements were obtained. The influence of technology innovation on environmental pollution not only includes production technology but also includes governance technology. Resource utilization efficiency can be improved by improving production technologies, thereby reducing resource consumption and environmental pollution. The improvement of governance technologies reduces environmental pollution by end treatment of pollutants. Porter et al. (1995) argued that enterprises can improve their productivity by reducing pollution, and reasonable environmental rules and policies can motivate enterprises to conduct technology innovation and improve the economic performance of enterprises. By taking R&D expenditures of enterprises and quantity of successfully applied patents as measurement indexes of technology innovation, Jaffe et al. (1997) deemed that creative output within the industry and environmental governance cost had no inevitable association. Brunnermeier et al. (2003) used data of the American manufacturing industry from 1983 to 1992 to conduct an empirical study, and results showed that environmental innovation positively contributed to decreased expenditures on environmental pollution control. Kemfert (2005) evaluated costs of environmental pollution reduction in different countries, analysed the relationship between capital input into enterprise technology progress and energy utilization efficiency, and found that enterprises should reinforce expenditures on technology progress to reduce pollution governance cost in essence. Horbach (2008) deemed that enterprises improved technical skills by R&D or further education measures, which would induce environmental pollution and can effectively promote enterprises to implement environmental pollution governance. Liu et al. (2012) measured technical efficiency in China's industrial environment during 2001-2008, and study results indicated that environmental technical efficiency presented a rising tendency in recent years, but the coordination gap between industries was large. Perino et al.

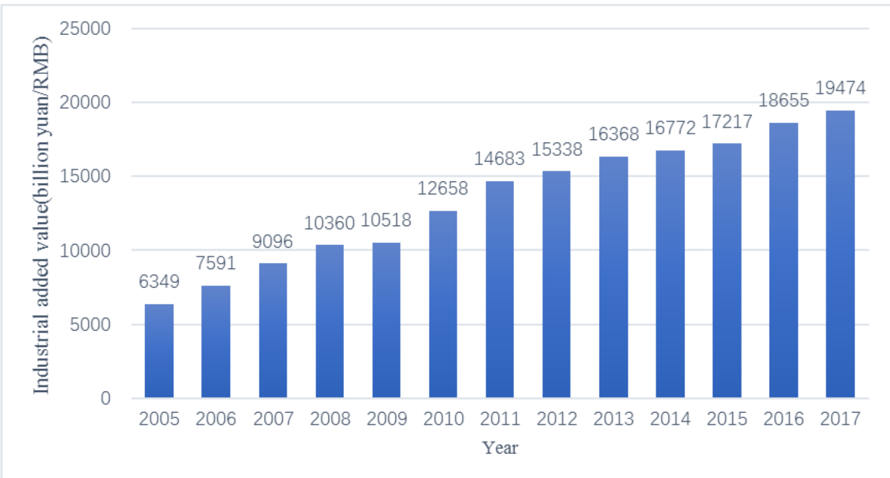

Fig. 1: Industrial value added in Zhejiang Province between 2005 and 2017.
(Data source: *China Statistical Yearbook* (2006-2018))

(2012) indicated that the relationship between policy stringency and technical adoption rate presented an inverse U-type. Horbach et al. (2013) thought that if the enterprise introduced clean technologies for process innovation, its internal employment rate would be higher, and this process innovation would contribute to saving enterprise cost and improving its profitability and competitiveness. Ghisetti et al. (2014) deemed that both type and driving force of environmental innovation would influence the relationship between enterprise competitiveness and environmental performance, and the technology innovation by reducing use amount of energy materials can generate a positive influence on enterprise competitiveness. Zhao et al. (2016) though that environmental regulation generated a significant positive influence on enterprise innovation, and enterprises can effectively improve enterprise competitiveness by elevating the degree of innovation. Chen et al. (2016) deemed that technology innovation can more be influenced by resource protection and can result in a declining tendency of use of precious metals like gold. Alvarez-Herranz et al. (2017) verified the positive influence of energy innovation process on the improvement of environmental pollution. Johnstone et al. (2017) deemed that relative to end pollution governance technology, innovation of governance technology can improve enterprise pollution governance efficiency more. Existing studies indicate that technology innovation has social characteristics of environmental protection effect and energy conservation and emission reduction. Enterprises can further improve enterprise production efficiency by environmental technology innovation. Moreover, they can save resources to obtain cost advantages. Thus, enterprise pollution can be improved, which then can contribute to the development of ecological environment and the resolution of the contradiction between economic development and environmental protection. We analysed whether the technology innovation level of industrial enterprises can effectively relieve environmental pollution. Then, technology innovation measures for governing environmental pollution of industrial enterprises were proposed.

MODEL PROFILE AND DATA DESCRIPTION

Model profile: To study the influence of technology innovation on regional environmental pollution in prefecture-level cities in Zhejiang Province, we should not only consider transverse individual differences of each region like differences in enterprise R&D expenditures in each typical province and city, but we also consider that macro policies faced by each region at different time points are different such as industrial policy, environmental protection policy, and local policy, all of which can generate highly important influences on regional environmental conditions. Both, the time factor and individual differences are considered in this study. Thus, panel data are used for the analysis. The panel data model not only uses many samples during statistical analysis, but also reduces the multi-collinearity problem, which is commonly used in the multiple regression analysis, and model estimation results are reliable. Zhenjiang Province is located on the east coast of China. The province has 11 prefecture-level cities of statistical significance. Industrial wastewater discharge (Y1), industrial waste gas discharge (Y2), and industrial solid waste discharge (Y3) are used as explained variables, and technology innovation index (X1) of large- and medium-sized industrial enterprises are used as explaining variables. The general form of panel data is as follows:

$$\begin{aligned} Y_{it} &= a_{it} + X_{it}\beta_{it}\varepsilon_{it} \\ X_{it} &= (X_{1it}, X_{2it}, \cdots X_{kit}) \\ \beta &= (\beta_{1i}, \beta_{2i} \cdots \beta_{ki}) \\ i &= 1, 2 \cdots N ; t = 1, 2 \cdots T \end{aligned} \quad ...(1)$$

In Equation (1), α_i is an intercept term, β_i is an explaining variable coefficient, ε_{it} is white noise, and K is the number of explaining variables. According to the different hypotheses of α and β, the model is divided into three forms, as shown in Equation (2):

$$\begin{aligned} &\text{Hybrid data model: } \alpha_i = \alpha_j, \beta_i = \beta_j \\ &\text{Variable} - \text{intercept model: } \alpha_i \neq \alpha_j, \beta_i = \beta_j \\ &\text{Variable} - \text{coefficient model}: \alpha_i \neq \alpha_j, \beta_i \neq \beta_j \end{aligned} \quad ...(2)$$

Prior to panel model regression, which model to be used concretely should be initially judged. The extensively used covariance analysis is used in this paper for testing. In this method, we conduct tests mainly by two F statistical quantities to judge which model to use for regression:

$$F_1 = \frac{(S_2 - S_1)/(N-1)K}{S_1/[N(T-K-1)]} \sim F[(N-1)K, N(T-K-1)] \quad ...(3)$$

$$F_2 = \frac{(S_3 - S_1)/(N-1)(K+1)}{S_1/[N(T-K-1)]} \sim F[(N-1)(K+1), N(T-K-1)] \quad ...(4)$$

Where, S_1, S_2 and S_3 and are residual sums of squares of Equation (3)-(4) that correspond to three formulas; N is number of cross sections of studied data; T is time span; and K is number of independent variables. α =0.01 , it refers to the significance level. Statistical quantity F_2 is first used to determine whether a hybrid model is suitable. If F_2 is smaller than the critical value, a hybrid data model will be used, or can be used for further tests. If F_1 is smaller than a critical value, then the variable-intercept model will be used, F_1 or otherwise, the variable-coefficient model will be used.

After the concrete model section, fixed effect and random effect will be selected. The generally used method is Hausman test. The statistical quantity W is established, as shown in Equation (5):

$$W = [b - \hat{\beta}]\hat{\Sigma}^{-1}[b - \hat{\beta}] \quad ...(5)$$

Where, b is the estimated regression coefficient of the fixed effect and $\hat{\beta}$ is the estimated regression coefficient of random effect. $\hat{\Sigma}$ is the variance of the difference between the two models in regression coefficients, namely, $\hat{\Sigma}$ =var ($\alpha - \hat{\beta}$). When the original hypothesis holds, W follows Chi-square distribution with a degree of freedom of K. Under the given significance level, $\alpha = 0.01$ is generally used. If the value of the statistical quantity W is greater than the critical value, the fixed-effect model will be selected, or otherwise, the random-effect model will be used.

Data description: At present, industrial pollution has become the leading pollution source of eco-environmental pollution in Zhejiang Province. The present industrial pollution mainly includes the discharge of industrial wastewater, waste gas, and industrial solid waste. Industrial wastewater discharge (Y1), industrial waste gas discharge (Y2), and industrial solid waste discharge (Y3) in 11 prefecture-level cities in Zhejiang Province are used as explained variables. R&D expenditure reflects the importance degree attached by a region to enterprise technology innovation and embodies enterprise innovation capacity and technological level. R&D expenditure of large- and medium-sized industrial enterprises in different cities is used in this paper to express technology innovation index (X1) of large- and medium-sized industrial enterprises, which is taken as the explaining variable. Cross-sectional data of both time series and panel series are selected in this paper. Panel data of 11 prefecture-level cities in Zhejiang Province during 2005-2016 are selected for empirical analysis. The "three-waste" discharges and R&D expenditures of large- and medium-sized industrial enterprises in 11 prefecture-level cities in Zhejiang Province derive from *Zhejiang Statistical Yearbook*.

RESULTS ANALYSIS

Industrial wastewater discharge, industrial waste gas discharge, and industrial solid waste discharge are set as industrial "three-waste" pollution indexes. E Views 9.0 is used to establish panel data regression models of influence factors of environmental pollution respectively. The variable-coefficient model of random effect is determined, and the results are obtained (Table 1).

As shown in Table 1, enterprise R&D expenditure in most cities in Zhejiang Province is negatively correlated with environmental pollutant discharge, and the influence is significant, namely, the greater the R&D expenditure, the smaller the environmental pollutant discharge. Most adjusted R squares are greater than 0.7, which indicates that the fitting effect of the model is favourable. Therefore, we verified that industrial enterprises in Zhejiang Province actively organize technology innovation activities, increase R&D expenditure, and study new technologies and processes. On the one hand, environmental pollutant discharge can be reduced. On the other hand, enterprise pollution treatment level and pollutant recycling rate can be improved. Different cities have varying regression coefficients, and the regression coefficients of some cities are insignificant, which indicates that large- and medium-sized industrial enterprises in the cities attach different importance degrees to enterprise R&D expenditures, so effects and significance levels generated by influence factors on environmental pollution in the cities are different. The influence of technology innovation input of industrial enterprises in Hangzhou, Ningbo, Wenzhou, Huzhou, and Taizhou on reduction of their industrial pollutant discharge is obvious. These cities belong to cities in Zhejiang Province with good economic foundations with many industrial enterprises. Thus, R&D expenditure base of large- and medium-sized industrial enterprises is substantial. For these cities, conducting industrial structural adjustment, developing key environmentally friendly industrial enterprises and forming local characteristics are necessary. The influence of technology innovation input of industrial enterprises in Quzhou, Zhoushan, and Lishui on the reduction of their industrial pollutants is not obvious, possibly because the three cities focus more on the traditional manufacturing industry while ignoring the distribution of high-tech industrial enterprises. Few R&D expenditures occur in industrial enterprises. Thus, R&D has not obviously supported the reduction of environmental pollutants, and incomprehensive enterprise technology innovation is a key factor that restricted the reduction of industrial pollutants in the three cities.

POLICY SUGGESTIONS

Strengthen the degree of governmental support for independent innovation of industrial enterprises: Governments at all levels in Zhejiang Province should increase technology innovation input, not only with a single increase of R&D expenditure, but by considering multiple measures to exert joint effects, thereby realizing accurate support of technology innovation. They should encourage scientific R&D input and allow pre-tax deduction of technology development costs of industrial enterprises, support industrial enterprises to establish R&D institutions or scientific research centres, encourage industrial enterprises with conditions to establish their technology R&D centres, encourage industry-university-research cooperation, and establish R&D cen-

Table 1: Regression results of industrial "three wastes".

Variable/City	Regression coefficient (Y1)	Regression coefficient (Y2)	Regression coefficient (Y3)
C	3.01**	0.75**	7.52**
Hangzhou	0.23**	0.74**	0.12**
Ningbo	0.04***	0.62***	0.21**
Wenzhou	-0.75**	-0.32***	-0.74**
Jiaxing	-0.24**	-0.98***	-0.14
Huzhou	0.21**	0.41**	0.01**
Shaoxing	-0.28***	0.07*	-0.08
Jinhua	0.04	0.45***	0.47***
Quzhou	0.67	0.14***	-0.04
Zhoushan	-0.96	-0.57**	-0.47
Taizhou	-0.35***	0.08***	0.07***
Lishui	-0.44***	0.37	-0.78
Adjusted R^2	0.72	0.74	0.73

(*** means significant under 1% confidence level, ** means significant under 5% confidence level and * means significant under 10% significance level)

tres with universities and colleges and scientific research institutions in order to improve their independent innovation capabilities. Other initiatives include encouraging formulation of technology R&D and environmental technical standards, adopting reduction and exemption policies or giving subsidies to individuals or enterprises to apply for and maintain domestic and foreign invent patents according to related stipulations, reducing unnecessary declaration procedures and promote scientific R&D output, encouraging industrial enterprises with patented technologies to participate in formulating industrial standards and jointly maintain intellectual results, giving a certain proportion of reimbursement to industrial enterprises for expenses used to participate in formulation of technical standards, encouraging small- and medium-sized enterprises to independently participate in technology development, and forcing large-scale industrial enterprises to prioritize technology innovation, thereby forming a favourable innovation atmosphere within the industry.

Encourage sharing-type development of technologies of industrial enterprises: We should establish innovation industrial parks and enhance clustering of industrial enterprises in China to realize sharing-type development. We should also encourage R&D teams to conduct cooperative development, resource sharing, and scientific and technological achievements sharing to improve the overall technology innovation efficiency in the industry. Thus, resources can be recycled, and pollution discharge can be reduced. Resources of upstream and downstream industries, such as the coal industry and power generation industry, can be integrated to form resource recycling, which can reduce pollutant and waste discharge. The integration of industry + tourism or cultural industry can not only result in technology innovation resources to industrial enterprises but can also realize transformation and upgrading of industries. We should check and assess overall green technology innovation efficiency of industrial parks, award industries with high overall green technology innovation efficiencies, and encourage innovation and green development. We should also encourage technical teams in industrial parks to realize sharing-type development, jointly establish R&D centres, break through technical bottlenecks of single enterprises, and conduct technology sharing and risk sharing to create an industrial park governance pattern featuring "co-build, co-govern, and sharing."

Encourage pollution governance technology innovation of industrial enterprises: Given that Zhejiang Province continues to centre on industrial enterprises and the province remains insufficiently powerful to improve industrial "three-waste" discharge only by enhancing investment measures on industrial pollution governance, reinforcing front-end defensive power, increasing R&D input, actively introducing scientific and technological talents, improving effective transformation rate of scientific research achievements, and applying them quickly to actual production is necessary. Enterprise technology innovation is the most effective and advantageous path to reduce environmental pollution and realize energy conservation and emission reduction. Thus, governmental departments should also provide positive policy encouragement to enterprises. Examples of encouragement include giving preferential tax policies to enterprises with good technology innovation results and active innovation consciousness. For enterprises that lack independent innovation capabilities, governments can provide certain capital support so that they will be able to introduce advanced technical equipment to reduce environmental pollutant discharge.

Cultivate talents for environmental pollution control in industrial enterprises: We should innovate talent strategies and encourage overall innovation, which, on the one hand, can create an overall innovation environment of enterprises to reinforce the overall innovation atmosphere within the industry. On the other hand, this approach can elevate the proportion of technicians in China's industrial enterprises who participate in R&D and overcome unbalanced development between R&D teams to elevate the overall R&D level of enterprises. We should also innovate talent structure, incentive measures, and recruitment strategies, select technicians with high innovation spirit and technical strength, retain talents, and link technological achievements with personal performance. We should implement the patent sharing system and strengthen innovative impetus of technicians, which can also strengthen technology innovation capabilities of enterprises. Furthermore, we should persist in correct talent use, motivate talent, and establish a scientific talent selection and employment mechanism.

CONCLUSIONS

Unreasonable investment structure on environmental pollution and resource allocation disallows environmental governance input to reach an expected effect. Thus, increasing the investment amount on environmental governance is insufficient. Under an international environment with increasing fierce scientific and technological competitiveness, we should enhance the technology innovation power of industrial enterprises and attach importance to the improvement of environmental pollution governance efficiency because of enterprise R&D expenditure and scientific and technical personnel. In addition, improvement of environmental pollution of industrial enterprises can be realized to the greatest extent only by increasing the input and support of environmental protection technology and R&D input. By taking Zhejiang Province in China as an example, the influence of R&D expenditure of large- and medium-sized enterprises on industrial "three-waste" discharge was estimated based on the panel data of 11 prefecture-level cities in Zhejiang Province during 2005-2016. Technology innovation measures for environmental pollution governance of industrial enterprises were given. Our study results are as follows. Enterprise R&D expenditure in most cities in Zhejiang Province is negatively correlated with environmental pollution control of industrial enterprises, and the influence is significant. The influence of technology innovation input on the reduction of industrial pollutant discharge in industrial enterprises is obvious in Hangzhou, Ningbo, Wenzhou, Huzhou, and Taizhou by virtue of favourable economic foundations. We suggest that in-depth studies be conducted on aspects of transition of development patterns of China's industrial enterprises, knowing how the government should establish long-term mechanisms for energy conservation and emission reduction policies and regulations, whether the effect of scientific and technological capital input on environmental pollution governance within the industry has spatial differences, and establishment of the market demand mechanism for environmental technology innovation, among others.

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