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Environmental Regulation, Manufacturing Technological Progress and Pollution Emissions: Empirical Evidence from China

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Abstract: Based on the provincial panel data of China from 2004 to 2020, this paper uses the empirical model of mediating effect to theoretically analyze and empirically test the mechanism of environmental regulation affecting pollution emissions, and the mediating effect of manufacturing technology's progress. The study of this paper found that the improvement of pollution treatment technology is not the only technical means to reduce the level of pollution emissions. The progress of manufacturing production technology has a crucial role in promoting the reduction of pollution emissions. The high-quality development of the manufacturing industry and the improvement of the production technology level means that pollution emissions can be effectively reduced from the source. At the same time, although environmental regulation can have a significant positive impact on reducing pollution emissions, the progress of manufacturing production technology is a crucial intermediary variable for environmental regulation to promote pollution reduction. The above research conclusions have passed the influence mechanism test of this paper. Through the heterogeneity test, this study also found that in the stage of higher manufacturing development scale and technology level, manufacturing technology progress' intermediary role as an environmental regulation affecting pollution emissions, is more apparent, and the role of environmental regulation in promoting pollution reduction is more prominent. The degree of effect increases with the improvement of the production technology level of the manufacturing industry. After the robustness test, the research conclusion of this paper is still valid. According to the conclusions of the research, this paper puts forward policy suggestions that should be oriented to promote the upgrade of manufacturing technology, introduce environmental regulation policies, support manufacturing enterprises to increase the innovative application of energy-saving and emission-reduction technologies, and vigorously develop and expand high-tech manufacturing.

Keywords: environmental regulations; manufacturing; technological progress; pollution emissions; China

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1. Introduction

Global environmental governance and the healthy and sustainable development of the manufacturing industry are still facing a relatively difficult situation. How to strike a reasonable balance between "protecting the ecological environment" and "promoting the healthy and sustainable development of the economy" is an unavoidable problem for many countries. As the "calcium" of the economy, manufacturing plays an irreplaceable role in promoting a country's economic growth, promoting technological innovation, and reducing pollutant emissions. With the strengthening of the international consensus on reducing carbon emissions, and climate change, environmental regulations will be increasingly strict. The pressure of manufacturing transformation and upgrade will gradually increase, which will be more evident in developing countries [1–3]. The traditional view is that pollution treatment technology is the leading technology to reduce pollutant emissions. The manufacturing industry is regarded as a production activity accompanied by pollutant production, which is not consistent with reality. The academic circle has ignored the positive side of manufacturing production technology to reduce pollution emissions for a long time, which is not conducive to the healthy and sustainable development of the manufacturing industry. Judging from the practice of China's manufacturing industry, China has jumped out of the past development mode of "manufacturing industry development and environmental pollution" accompanied by each other, and is walking down a new manufacturing industry development road, in which "manufacturing industry development and pollution reduction" promote each other, changing our traditional understanding of the relationship between the manufacturing industry and pollution emissions. However, the current academic research on this aspect is lagging and lacking, and there is no academic explanation. In addition, as the most important factor affecting pollution reduction, the positive impact of environmental regulation on manufacturing production technology's progress, and the positive effect of manufacturing production technology's progress on reducing pollutant emission, cannot be ignored. According to the "Porter hypothesis" theory, environmental regulation can force manufacturing enterprises to carry out technological innovation to improve environmental quality, achieve the "harmonious coexistence" of environment and industrial development [4], and encourage manufacturing enterprises to improve production process levels and production efficiency [5]. In other words, while reducing pollutant emissions, environmental regulation will also have a significant impact on the production technology's level in the manufacturing industry, and the production technology's progress in the manufacturing industry can also have an impact on the reduction of pollutant emissions. The production technology's progress in the manufacturing industry plays an essential bridge function in environmental regulation and the promotion of pollutant emission reduction. However, at present, there is no academic research on the theoretical analysis and empirical test of the positive role of environmental regulation in promoting the improvement of manufacturing production technology, nor is there research into the impact of environmental regulation on the progress of manufacturing production technology in the process of promoting pollution reduction. This urgently needs to be answered academically.

In this context, this study focused on the above problems to examine and re-examine the critical role and value of manufacturing technology's progress in reducing pollution emissions, and analyze the mediating effect of manufacturing production technology's progress upon environmental regulation that promotes pollution reduction.

2. Literature Review

The relationship between environmental regulation, technical efficiency, energy conservation, and emission reduction, has always been one of the focuses of academic research. The famous "Porter hypothesis" propounds that, under dynamic conditions, both the improvement of environmental quality and the technical efficiency of the manufacturer can achieve a win–win situation [6]. Murty and Kumar [7] found that with the continuous enhancement of environmental regulation, the level of production technology will also continue to improve, and the conclusion of this study is consistent with the Porter hypothesis. Based on the model derivation results, Mohr [8] demonstrated that the improvement of endogenous technology could achieve pollution reduction and environmental quality improvement. However, when considering the learning effect and nonlinear effect, it is found that it is not easy to effectively balance the improvement of environmental quality with the technical efficiency of the manufacturer [9].

From the perspective of the relationship between environmental regulation and the manufacturing industry, the former has an inverted "U" shape on the latter. Specifically speaking, in the primary development stage of the manufacturing industry, environmental regulation negatively affects the manufacturing industry and its total factor productivity. With the continuous improvement in the scale and technological level of the manufacturing industry, the positive effect of environmental regulation on the total factor production efficiency of the manufacturing industry will become more and more apparent when it reaches a certain standard [10]. Grossman and Krueger [11] found that production technology, economic aggregate, and economic structure can affect the environment. With the continuous growth of a country's economy and the increase of per capita income, when a certain critical point is reached, the impact of industrial development on environmental pollution will change from a negative effect to a positive effect. Reasonable environmental regulation will not inhibit the development of the manufacturing industry and economic growth can only improve the environment and economic development, promoting the optimization and upgrade of the industry [12–16].

The environmental regulation can also promote the optimization and adjustment of the industrial structure of the manufacturing industry, transform existing manufacturing technologies, add new advanced manufacturing technologies, continuously increase the proportion of high-end manufacturing and high-efficiency manufacturing [17], to realize the elimination and "clearance" of high energy consuming and high-polluting manufacturing enterprises, and enhance the advanced level and rationalization level of the manufacturing structure [18,19]. With the improvement of the technological level of the manufacturing industry, the production efficiency of the manufacturing industry will also increase. The efficiency of its transformation and utilization of market resources will be enhanced, which can effectively suppress and reduce the pollution of manufacturing production from the root cause, and reduce the actual emission of pollutants [20,21].

Air pollution poses significant harm to human health. The air pollution caused by production mode cannot be ignored and efforts should be made to solve environmental problems such as air pollution [22,23]. The optimization of manufacturing structure, the progress of manufacturing technology, and the improvement of pollution control technology are all conducive to the reduction of manufacturing pollution emissions. Still, technological progress plays a dominant role in promoting energy conservation and emission reduction [24]. The efficient utilization of production resources depends on improving manufacturing technology and reducing manufacturing pollution emissions [25]. It can be said that the most effective way to reduce the emission of pollutants in the manufacturing industry is to reduce the amount of pollutants produced, and the biggest driving force behind reducing the amount of pollutants produced is improving the production technology level of the manufacturing industry [26]. We have sorted the basic information of the key literature, as shown in Table 1.

To sum up, other studies have confirmed the positive effects of environmental regulation on manufacturing technology's progress and pollution reduction and have also analyzed the promoting effect of technology level on pollution reduction. However, there are also obvious deficiencies in other existing studies. On the one hand, other existing studies are limited to solely analyzing the impact of environmental regulation on pollution reduction or technological progress on pollution reduction. The internal relationship and mechanism among environmental regulation, manufacturing technology's progress, and pollution reduction have not been analyzed from a systematic and overall perspective. In addition, there is no specific research on the mediating effect of manufacturing technology's progress in environmental regulation promoting pollution reduction.

On the other hand, other existing studies focus on analyzing the effect of pollution control technology on pollution reduction. Some of the literature does not indicate whether the technology affecting pollution emissions is production or control technology. There is no literature to analyze and study the positive effect of manufacturing production technology on pollution reduction.

Table 1. Basic information of the key literature.

Study Area (Place)	Pollutant Types	Key Observations	Author (Year)
America	Industrial environmental pollution	The relationship between technical efficiency and pollution control	Porter M.E. [6]
America	Industrial environmental pollution	Industrial development has an impact on environmental pollution	Grossman and Krueger [11]
America	Industrial environmental pollution	Improving technology can promote pollution reduction	Mohr [8]
Austria	Industrial environmental pollution	The improvement of environmental pollution and the improvement of technical efficiency needs reasonable consideration	Feichtinger et al. [9]
India	Air Pollution	There is a correlation between reducing air pollution and improving technology	RP Kumar, SJ Perumpully et al. [23]
India	Agricultural, environmental pollution and air pollution	There is a strong correlation between production technology and air pollution	Sneha Gautam, Adityaraj Talatiya et al. [22]
China	Industrial environmental pollution	Manufacturing technology is conducive to reducing the production and emission of pollutants	Peng and Gan [20]
China	Industrial environmental pollution	Manufacturing technology can help reduce pollutant production and emissions	Zhong and WEI [21]
China	Industrial environmental pollution	Manufacturing technology can promote pollution reduction	Li and Zhao [24]
China	Industrial environmental pollution	Manufacturing technology can reduce pollution and emissions	Yuan and Xie [25]
China	Industrial environmental pollution	Manufacturing production techniques can reduce pollutant production	Wang and Tian et al. [26]

Compared with other similar studies, this paper is unique in terms of research perspective and content, which are also aspects the innovation and uniqueness of this paper. From the perspective of research, this paper studies the internal relationships and mechanisms in environmental regulation, the technological progress in the manufacturing industry, pollution emissions from an overall and systematic perspective, and includes the technological level of manufacturing industry into the research framework of environmental regulation affecting pollution reduction, thus enriching and improving the existing academic research scope and perspective. From the perspective of research content, the manufacturing technology's progress mentioned in this paper refers to the progress of production technology in the manufacturing industry, which is completely different from pollution control technology. Therefore, this paper focuses on the study and analysis of the influence of production technology's progress in the manufacturing industry on pollution reduction, and the mediating effect of production technology's progress in the manufacturing industry on the process of environmental regulation promoting pollution reduction.

The contribution of this study to the existing literature is that it can effectively make up for the shortcomings and limitations of other similar studies; it can also improve and complement the academic research achievements in the field of environmental governance, pollution reduction, and sustainable development. Further, it expands the research scope of the interaction mechanism between manufacturing technology's progress, environmental regulation, and pollution reduction. It encourages the academic and practical circles to further understand and pay attention to the positive impact and important value of the high-quality development of both the manufacturing industry and production technology' progress on environmental improvement and pollution reduction. Moreover, it puts pressure the academic circle to carry out continuous, in-depth and academic research and an exploration of the theory and application of manufacturing technology's progress to promote pollution reduction and environmental improvement.

3. Material and Methods

3.1. Analysis of the Theoretical Mechanism of Environmental Regulation and Technological Progress in the Manufacturing Industry Affecting Pollutant Emission

Assuming that the manufacturing industry contains "n" manufacturing sectors, the total pollutant emissions of all manufacturing sectors is the emission of the entire manufacturing industry. If P_d represents the actual pollutants emitted by the manufacturing industry, and p_i represents the actual pollutants emitted by each manufacturing sector, then:

$$P_d = \sum_{i=1}^{n} p_i \tag{1}$$

Further, if U represents the total output value of the manufacturing industry, u_i represents the output value of each manufacturing sector, e_i represents the pollution emission intensity of each manufacturing sector, and θ_i represents the proportion of the output value of each manufacturing sector in the total output value of the manufacturing industry, then according to the decomposition analysis method established by Levinson [27] and Li Bin [24], it can be decomposed into:

$$\theta_i = u_i / U \tag{2}$$

$$e_i = p_i / u_i \tag{3}$$

$$p_i = U \times e_i \times \theta_i \tag{4}$$

$$P_d = \sum_{i=1}^{n} U e_i \theta_i \tag{5}$$

where t_i represents the pollutants produced by each manufacturing sector, $AD_i = t_i/u_i$, $AC_i = p_i/t_i$, then:

$$e_i = p_i / u_i = \frac{t_i}{u_i} \times \frac{p_i}{t_i} = AD_i \times AC_i \tag{6}$$

AD_i reflects the production technology level of the manufacturing industry. The lower the value, the higher the level of the production technology's progress; AC_i reflects the level of pollution control technology. The lower the value, the higher the level of pollution control technology.

At the same time, due to

$$p_i = e_i \times u_i = U \times \theta_i \times e_i \tag{7}$$

After substituting Equation (6) into Equation (7), we can get:

$$p_i = e_i \times u_i = U \times \theta_i \times AD_i \times AC_i \tag{8}$$

Taking the logarithm of both sides of Equation (8), we get:

$$\ln p_i = \ln U + \ln \theta_i + \ln AD_i + \ln AC_i \tag{9}$$

Based on the above, it can be concluded that:

$$P_d = \sum_{i=1}^{n} U \times \theta_i \times AD_i \times AC_i = U \sum_{i=1}^{n} \theta_i \times AD_i \times AC_i \tag{10}$$

It can be seen that the level of pollution emission intensity is not only affected by the level of pollution control technology, but also by the level of manufacturing production technology's progress. High-level manufacturing production technology can effectively reduce the amount and actual emission of pollutants and the emission of pollutants from the source. AC_i represents the level of environmental regulation and AD_i represents the level of technological progress in manufacturing. In other words, both environmental regulation and technological progress in manufacturing can have an important impact on pollutant emissions. The lower the values of AC_i and AD_i are, the higher the level of environmental regulation and technological progress in production.

3.2. Analysis of the Theoretical Mechanism of Environmental Regulation Affecting Manufacturing Technology's Progress

The theoretical derivation of the impact of environmental regulation on manufacturing technology's progress in this paper is based on the "production–pollution" theoretical model constructed by Copeland and Taylor [28]. According to this theoretical model, pollutants can be regarded as a product produced along with the production process of product M. The emission of pollutants is expressed by P. It is assumed that product M is a capital-intensive product and satisfies the condition of constant returns to scale. Since pollutants have negative externalities on the environment, manufacturing enterprises must pay certain costs for pollutant discharge as a price for damaging the environment. Such costs are called environmental taxes and are represented by t. Therefore, rational manufacturing enterprises will not put all production factors into product M, but devote part of their resource factors to pollutant control.

If the manufacturing enterprise invests all the resources into producing product M, the potential output can be Q. The manufacturing enterprise can only invest a certain proportion of production factors to produce M, and the proportion of production factors invested in M is denoted as w. The proportion of factors invested in pollutant control is $(1 - w)$. Then we can get:

$$M = (1 - w)Q \tag{11}$$

$$P = f(w)Q \tag{12}$$

where $f(w)$ is the minus function of w as the independent variable. Assuming:

$$f(w) = (1 - w)^{1/\alpha}/AD \tag{13}$$

where AD represents production technology, $0 < \alpha < 1$

According to Equations (12) and (13), we can get:

$$P = Q(1 - w)^{1/\alpha}/AD \tag{14}$$

According to Equations (11) and (14), we can get:

$$M = (P \times AD)^{\alpha} Q^{1-\alpha} \tag{15}$$

It can be found that the output of product M not only depends on the potential output, but is jointly affected by pollutants and production technology level. It can also be found that α represents the cost share of pollution control.

Therefore, to minimize the production cost c_M of M, a manufacturing enterprise also needs to minimize the production cost c_Q of potential production Q. In the presence of an environmental tax, we can get:

$$c_M = t \times P \times AD + Q \times c_Q \tag{16}$$

According to Equations (15) and (16), and the first derivative of Equation (16), we can get:

$$\frac{(1-\alpha) \times P \times AD}{\alpha \times Q} = \frac{c_Q}{t} \tag{17}$$

Assuming that M is in a perfectly competitive market, since the profit of the manufacturing enterprise is equal to 0, then:

$$M \times R = c_Q \times Q + t \times P \times AD \tag{18}$$

Using R to represent the price of product M, the calculation formula of pollution emission intensity e can be obtained as follows:

$$e = \frac{P}{M} = \frac{\alpha \times R}{t \times AD} \tag{19}$$

Pollution emission intensity reflects the level of environmental regulation. A high level of environmental regulation means that the value of e is relatively small.

According to Equation (19), it can be obtained as:

$$AD = \frac{\alpha \times R}{t \times e} \tag{20}$$

Equation (20) shows that the manufacturing industry's production technology's progress level AD is inversely related to e, which reflects the environmental regulation level. The strict environmental regulation level can promote the production technology's progress in the manufacturing industry and vice versa. In a word, environmental regulations can significantly impact technological progress in manufacturing.

4. Research Design and Descriptive Statistics

4.1. Data Source

This paper takes 31 provinces (municipalities and autonomous regions) in China from 2004 to 2020 as research samples, and uses provincial panel data to conduct empirical tests. The original data used in this paper come from the "China Industrial Economic Statistical Yearbook", "China Environmental Statistical Yearbook", "China Statistical Yearbook", the National Research network database, the local Statistical Yearbook, etc. To ensure the integrity of the data, this paper used the interpolation method to complete the missing index data. Meanwhile, to eliminate the endogeneity problem between indicators, this paper processed the index data logarithmically.

4.2. Empirical Model Design

This paper takes pollutant emission as the explained variable, environmental regulation as the core explanatory variable, and manufacturing technology's progress as the intermediary variable to empirically test the impact of environmental regulation on pollutant emission and its mechanism. In this paper, the data of explained, core, explanatory, and control variables were logarithmically processed, and the empirical mediation effect model was adopted. The empirical models of the mediation effect designed in this paper are shown in Model (21), Model (22), and Model (23).

The empirical model of the mediation effect has prominent advantages. The empirical model of the mediation effect can effectively test whether there is a mediation effect between the explained variable and the explanatory variable. It can also identify the mediation effect variable so as to find the mechanism and path of influence of the explanatory variable on the explained variable. The disadvantage of the empirical model of mediation effect is that the actual operation is complicated and panel data is needed for verification.

$$PEI_{it} = \kappa_0 + \kappa_1 PCON_{it} + \kappa_2 INPAT_{it} + \kappa_3 INCO_{it} + \kappa_4 EDUC_{it} + \kappa_5 POPU_{it} + \mu_i + \gamma_t + \varepsilon_{it} \tag{21}$$

Model (21) was used to examine the direct effects of environmental regulations on pollution emissions. PEI is the explained variable, representing pollution discharge; PCON is the core explanatory variable and represents environmental regulation; INPAT, INCO, EDUC and POPU are control variables, respectively representing independent innovation level, per capita income level, education level and population size. I and t represent the region and year, respectively; μ_i represents the region fixed effect; γ_t represents the year fixed effect; and ε_{it} is the random disturbance term, which is assumed to be normally distributed at zero mean value and constant variance [29–32].

$$PROG_{it} = \beta_0 + \beta_1 PCON_{it} + \beta_2 INPAT_{it} + \beta_3 INCO_{it} + \beta_4 EDUC_{it} + \beta_5 POPU_{it} + \mu_i + \gamma_t + \varepsilon_{it} \tag{22}$$

Model (22) is used to test the impact of environmental regulations on manufacturing technology's progress. PROG is the explained variable and represents the technological progress of the manufacturing industry. The definitions of other variables and parameters are the same as in Model (21).

$$PEI_{it} = \alpha_0 + \rho PROG_{it} + \alpha_1 PCON_{it} + \alpha_2 INPAT_{it} + \alpha_3 INCO_{it} + \alpha_4 EDUC_{it} + \alpha_5 POPU_{it} + \mu_i + \gamma_t + \varepsilon_{it} \tag{23}$$

Model (23) tests the impact of environmental regulation and manufacturing technology's progress on pollution emissions. The definitions of other variables and parameters are the same as those of Model (21) and Model (22). Model (21), Model (22), and Model (23) can be used to test the mediating effect of manufacturing technology's progress in the process of environmental regulation affecting pollution emissions.

4.3. Selection of Variables and Definitions

4.3.1. Environmental Regulation

Existing methods for constructing environmental regulation indicators in the literature mainly fall into two categories: one is to construct proxy variables from the perspective of pollution control input, and the other is to construct proxy variables from the perspective of pollution control effect. This paper argues that it is better to construct proxy variables from the perspective of pollution control input to reflect the objective situation, because the essence of environmental regulation is to increase the cost of pollution emissions for enterprises. To reduce the costs caused by pollution emissions, enterprises should increase their investment in pollution control to reduce pollution emissions because the investment in pollution control can better reflect the ability of environmental regulation to restrict the emission of pollutants of enterprises. Given this, environmental regulation is measured by the intensity of pollution control investment. Specifically, environmental regulation is equal to the proportion of industrial pollution control investment expenditure in industrial added value.

4.3.2. Pollution Emissions

Pollutants discharged by the manufacturing industry mainly include sulfur dioxide, and soot and dust, among which sulfur dioxide is the majority. Considering data availability, this paper uses sulfur dioxide emissions from industrial production as the proxy variable of pollution emissions.

4.3.3. Technological Progress

Technological progress in the manufacturing industry mainly depends on technological innovation, which is reflected in the size of the R&D investment of manufacturing enterprises. R&D investment can effectively reflect the level of technological progress in manufacturing enterprises. Given the availability of data, this paper uses "R&D expenditure of industrial enterprises above designated size" as a proxy variable to measure technological progress in the manufacturing industry.

4.3.4. Control Variables

According to the above analysis, factors affecting pollution emissions also include scale factors. Meanwhile, informal environmental regulations, such as education level and income level, also impact pollution emissions. Therefore, the control variables used in this paper include independent innovation level, per capita income level, education level, and population size. Among them, the independent innovation level takes "the number of authorized invention patents" as the proxy variable, the per capita income level takes "the average wage of urban employees" as the proxy variable, the education level takes "the number of people aged 6 and above who are in college or above" as the proxy variable, and the population size is equal to the number of permanent residents (Table 2).

Table 2. Definitions of variables.

Variable Type	Variable Name	Variable Symbol	Variable Definitions
Explained variable	Pollutant discharge	PEI	Sulfur dioxide emissions from industrial production
Core explanatory variable	Environmental regulation	PCON	Proportion of investment expenditure on industrial pollution control in industrial added value
Intermediate effect variable	Technological progress in manufacturing	PROG	R&D expenditure of industrial enterprises above the designated size
Control variables	Level of independent innovation	INPAT	Number of invention patents granted
	Per capita income level	INCO	Average wage of urban employees
	Level of education	EDUC	Population aged 6 years and above with college and above
	Population size	POPU	Number of permanent residents

4.4. Descriptive Statistics

Before the empirical test, it is necessary to conduct a descriptive statistical analysis for each variable. The results of the descriptive statistical analysis are shown in Table 3. According to the statistical analysis results, the observed values of the explained variable, the core explanatory variable, the mediating effect variable, and the control variable, are all 527. In the case of taking the logarithm of the original data of each variable, the maximum value and minimum values of each variable are between the maximum and minimum values. Most of the gaps are relatively large. At the same time, to test whether there is multicollinearity between various variables, this paper also conducts a multicollinearity test and analysis. The test results show that the mean VIF of each variable is 6.14, less than 10, indicating no multicollinearity between various variables.

Table 3. Summary of the Descriptive Statistics.

Variables	Observed Value	Mean	Standard Deviation	Minimum Value	Maximum Value
PEI	527	3.430767	3.430767	−2.302585	5.299317
PCON	527	11.56808	1.409977	3.561046	14.16367
PROG	527	13.54649	1.861264	2.302585	17.03437
INPAT	527	7.24038	1.844236	1.098612	11.16613
INCO	527	10.6576	0.6036433	9.380505	12.12825
EDUC	527	8.153475	1.341768	3.135494	12.15996
POPU	527	8.101585	0.8534887	5.621668	9.443324

Meanwhile, this paper also draws and analyzes the kernel density graph of proxy variables for pollution emissions, environmental regulation, and manufacturing technology's progress, as shown in Figures 1–3. It can be found that the kernel density plots of the three proxy variables are close to the normal distribution. The change characteristics in time are the same, and the correlation between variables is strong.

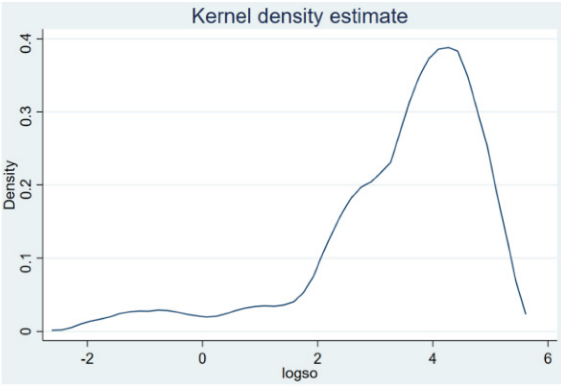

Figure 1. Kernel density map of proxy variables for pollution emissions.

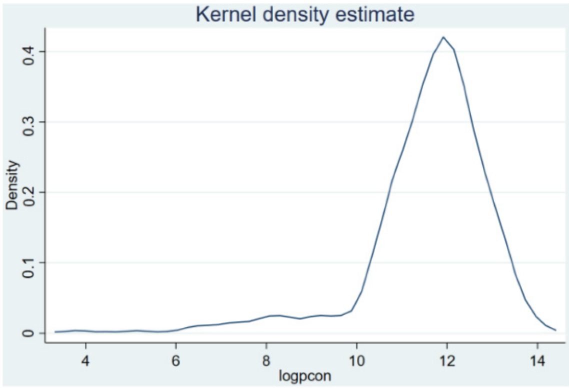

Figure 2. Kernel density map of proxy variables of environmental regulation.

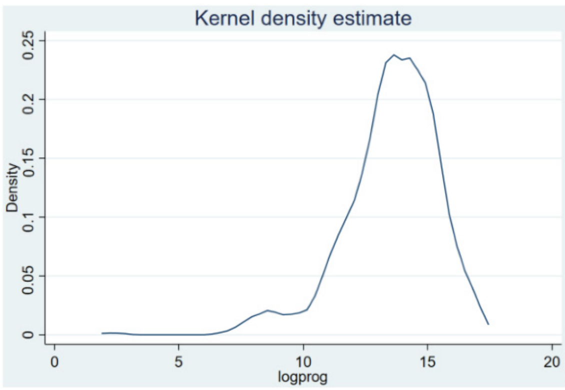

Figure 3. Kernel density plot of proxy variables of manufacturing technology's progress.

5. Results and Discussion

5.1. Environmental Regulation Affects Pollution Emissions

In the process of regression estimation, it is necessary to determine whether the fixed effects model or the random effects model is used. Whether the individual effects are correlated with the core explanatory variables is the assumed condition of the fixed effects model and the random effects model, respectively. If the fixed effects model is used, it is also necessary to determine whether there are only individual effects or whether there are both individual effects and time effects. Before using the Hausmann test to determine whether to use the fixed effects model, fixed effects regression and random effects regression should be conducted, respectively. Finally, the Hausmann test should be conducted according to the results of fixed effects regression and random effects regression. In Table 4, columns (3) and (4) report the regression results under double fixed and random effects, respectively. For comparison, mixed effects regression is also carried out in this paper, and the regression results are shown in column (1) of Table 4. In addition, regression estimation is also carried out considering only individual effects, and the regression results are shown in column (2) of Table 4.

Table 4. Impact of environmental regulation on pollution emissions.

Variables	**PEI**			
	(1)	**(2)**	**(3)**	**(4)**
PCON	−0.6207275 *** (−19.38)	−0.3715699 *** (−7.59)	−0.1566644 ** (−2.45)	−0.4295955 *** (−8.63)
INPAT	−0.2382426 *** (−5.83)	−0.0905795 * (−0.87)	−0.045571 * (−0.37)	−0.1334404 * (−1.71)
INCO	−0.8239383 *** (−8.98)	−0.8545957 *** (−4.27)	−0.7559474 * (−1.15)	−0.9353942 *** (−4.93)
EDUC	−0.1188867 *** (−3.74)	−0.0853676 *** (−4.40)	−0.6178827 * (−1.68)	−0.0919796 *** (−4.65)
POPU	0.489869 *** (7.03)	−1.626269 * (−1.87)	−1.490036 * (−1.45)	−0.5450468 *** (−3.51)
Enterprise individual	—	control	control	control
Annual time	—	—	control	control
Constant term	1.818259 (1.51)	21.3755 ** (2.62)	2.493851 (0.24)	4.23069 (1.59)
N	527	527	527	527
R^2	0.7874	0.0344	0.0047	0.7761

Note: (1)–(3) is the t value in parentheses; (4) is the z value in parentheses; ***, ** and * are significant at the confidence level of 1%, 5%, and 10%, respectively.

This paper uses different effect models to test the relationship between environmental regulation and pollution emissions empirically, and makes a comparative analysis. In the case of regression analysis with common standard error and fixed effects model, it is found that the p value of the F test is 0.0000. Therefore, fixed effects regression can be considered better than mixed effects regression. As for the impact of environmental regulation on pollution emissions, each region has its intercept term; that is, there is the regional effect, so mixed effect regression should not be used. When the time effect and regional effect are considered, the signs of the time dummy variables are all negative, but some of them are significant, and some are not. Therefore, the joint significance test of time dummy variables was conducted, and the p value was 0.0000, so there was a time effect.

This paper also a conducts random effects regression around the impact of environmental regulation on pollution emissions and then conducts an LM test. The test results show that there are random regional effects, so the random effects regression should be chosen between the random effects regression and the mixed effects regression. In addition, according to the regression results of the fixed effects model and random effects, the Hausmann test was conducted in this paper, and the result showed that the p value was 0.0000. Therefore, the null hypothesis was strongly rejected. That is, the fixed effects model should be used for regression analysis.

In conclusion, the impact of environmental regulation on pollution emissions has regional and annual effects. Therefore, a bidirectional fixed-effect model containing individual and time effects should be selected for the regression test. According to the results shown in column (3) of Table 4, after controlling variables such as independent innovation level, per capita income level, population factors, and regional effect and year effect, the impact of environmental regulations on pollution emissions presents a negative relationship. It is significant at a 1% confidence level, which is consistent with the expected relationship between the two. This indicates that reasonable pollution control and strict pollution control are conducive to reducing pollution emissions. Control variables, such as independent innovation level and per capita income level, are statistically significant at a 1% or 10% confidence level, indicating that the selected control variables are reasonable.

5.2. Impact of Environmental Regulation on Manufacturing Technology's Progress

The methods and steps for testing and analyzing the influence of environmental regulations on manufacturing technology's progress is the same. It is also necessary to test and choose between the fixed effect model and the random effect model, and whether there is a year effect in the fixed effect model. According to the above test methods, this paper conducted empirical tests, such as the joint significance test of year dummy variables, the LM test and Hausmann test, and found that there are regional and annual effects on the impact of environmental regulations on manufacturing technology's progress. A two-way fixed effect model should be selected for regression analysis. In Table 5, columns (5), (6), (7), and (8) report the mixed effects regression results, regional fixed effects regression results, two-way fixed effects regression results, and random effects regression results of environmental regulations on manufacturing technology's progress, respectively.

Table 5. Impact of environmental regulation on manufacturing technology's progress.

Variables	**PROG**			
	(5)	**(6)**	**(7)**	**(8)**
PCON	0.1567716 *** (7.15)	0.1350319 *** (5.34)	0.0888762 *** (3.28)	0.1567716 *** (5.78)
INPAT	0.3819354 *** (9.19)	0.2755783 *** (4.80)	0.3604874 *** (5.05)	0.3819354 *** (5.97)
INCO	0.5956726 *** (7.77)	0.8240867 *** (5.94)	0.9862756 * (1.80)	0.5956726 *** (4.23)
EDUC	0.0207984 (1.34)	0.0203361 ** (2.4)	0.1086004 (1.37)	0.0207984 ** (2.48)
POPU	0.948493 *** (9.80)	0.4732881 (0.73)	0.482366 (0.66)	0.948493 *** (6.46)
Enterprise individual	—	control	control	control
Annual time	—	—	control	control
Constant term	−4.895571 *** (−4.24)	−2.46222 (−0.52)	−5.369863 (−0.56)	−4.895571 *** (−2.80)
N	527	527	527	527
R^2	0.8950	0.8478	0.8853	0.8950

Note: (5)–(7) is the t value in parentheses; (8) is the z value in parentheses; ***, **, and * are significant at the confidence level of 1%, 5%, and 10%, respectively.

According to the regression results, no matter what model is used, the impact of environmental regulation on manufacturing technology's progress is significant at a 1% confidence level, showing a positive effect, indicating that environmental regulation has a positive impact on manufacturing technology's progress. Reasonable and strict environmental regulation is conducive to improving manufacturing technology's progress.

According to the results shown in column (3) of Table 5, after controlling the regional effect, year effect, and each control variable, the impact of environmental regulations on manufacturing technology's progress is still significant at the 1% confidence level.

5.3. Impact of Environmental Regulation and Manufacturing Technology's Progress on Pollution Emissions

This paper also empirically tests the mechanism of environmental regulation affecting pollution discharge and analyzes the mediating effect of manufacturing technology's progress in environmental regulation. The main research feature and highlight of this paper is the testing of the mechanism of environmental regulation affecting pollution emission, aiming to test and analyze whether the technological path of environmental regulation affecting pollution emissions is significantly manifested in the manufacturing sector. At the same time, following the above test methods, this paper conducts mixed effect regression, fixed effect regression, and random effect regression, focusing on the impact of environmental regulation and manufacturing technology's progress on pollution emissions and their paths. The regression results are shown in columns (9), (10), (11), and (12) in Table 6. Column (11) is the regression result considering the regional and year effects. In other words, after fixing the regional effect and year effect, the direct effect of environmental regulation on pollution emissions are significant at the confidence level of 5%, showing a negative effect. In addition, the influence of manufacturing technology's progress on pollution emissions are significant at the confidence level of 10%, which also presents a negative impact.

Table 6. Impact of environmental regulation and manufacturing technology's progress on pollution emission.

Variables	PEI			
	(9)	**(10)**	**(11)**	**(12)**
PCON	−0.5029285 *** (−13.48)	−0.3062818 *** (−4.77)	−0.145534 ** (−2.24)	−0.3444569 *** (−5.73)
PROG	−0.3238679 *** (−5.72)	−0.4835016 * (−1.80)	−0.1252351 * (−1.24)	−0.4453637 ** (−2.52)
INPAT	−0.4565214 *** (−8.3)	−0.223822** (−2.54)	−0.0907167 * (−0.85)	−0.3343587 *** (−3.51)
INCO	−0.8375722 *** (−9.4)	−1.253043 *** (−3.55)	−0.6324311 * (−1.06)	−1.142553 *** (−5.55)
EDUC	−0.1231158 *** (−3.98)	−0.0952001 *** (−5.65)	−0.6042821 * (−1.61)	−0.1007043 *** (−5.83)
POPU	0.3913796 *** (5.61)	−1.855105 * (−1.98)	−1.550446 * (−1.48)	−0.1689705 (−0.70)
Enterprise individual	—	control	control	control
Annual time	—	—	control	control
Constant term	1.282857 (1.10)	22.56599 ** (2.71)	3.166346 (0.29)	5.820685 ** (2.15)
N	527	527	527	527
R^2	0.8000	0.0006	0.0004	0.7857

Note: (9)–(11) is the t value in parentheses; (12) is the z value in parentheses; ***, **, and * are significant at the confidence level of 1%, 5%, and 10%, respectively.

In this paper, LM, Hausmann, and joint significance test of time dummy variables are conducted. The results show that p values are all 0.0000, indicating that environmental regulation and manufacturing technology's progress have regional and annual effects on pollution emissions. Therefore, two-way fixed effect regression is better than random and mixed effect regression. At the same time, from the perspective of the mechanism test, according to the above test results, environmental regulation has a negative impact on pollution emissions. The influence of environmental regulation on manufacturing technology's progress is positive, while the influence of manufacturing technology's progress on pollution emissions is negative. When the two are multiplied, the influence is negative, which is consistent with the influence direction of environmental regulation on pollution emission. It shows that the intermediary effect of manufacturing technology's progress on the environmental regulation of pollution emissions exists objectively and is a critical influence path.

5.4. Heterogeneity Test

5.4.1. Time Heterogeneity Test

Under the strictest parameter constraints, the study samples were divided into two periods, from 2004 to 2012 and 2013 to 2020, and the two-way fixed effect model was used for regression estimation. Column (13) of Table 7 reports the test results for the impact of environmental regulation and manufacturing technology's progress on pollution emissions from 2004 to 2012. Meanwhile, column (14) reports the test results of the impact of environmental regulation and manufacturing technology's progress on pollution emissions from 2013 to 2020. In contrast, under the condition of controlling the technological progress of the manufacturing industry, the impact degree of environmental regulation on pollution emissions during 2013–2020 was lower than that during 2004–2012, with a significant decrease. The impact of environmental regulation on pollution emissions during 2013–2020 is significant at a 1% confidence level, and the impact during 2004–2012 is not significant at a 10% confidence level. The possible reason for this is that with the improvement of manufacturing production technology, manufacturing production technology has an endogenous enhancement on pollution reduction. The influence of environmental regulation on pollution emissions is gradually weakened. In addition, the influence direction of environmental regulation on pollution emissions do not change in the two periods, and the negative influence remains unchanged.

5.4.2. Regional Heterogeneity Test

According to the classification of the National Bureau of Statistics of China, the research samples are divided into three regions: eastern, central, and western regions. Eleven regions are located in eastern China, including Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, and Hainan. The central region of China consists of eight regions, namely Shanxi, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei and Hunan; Western China consists of 12 regions, namely Sichuan, Chongqing, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang, Guangxi and Inner Mongolia. The regression estimation of the eastern, central, and western regions is carried out. Table 7, columns (15), (16), and (17), respectively, show the test results for the impact of environmental regulation and manufacturing technology's progress on pollution emissions in eastern, central and western regions. By comparison, we can find that the impact of environmental regulation on pollution emissions in the eastern region is weaker than that in the central and western regions. In comparison, the impact of manufacturing technology's progress on pollution emissions is stronger than that in the central and western regions. The reason for this is that the eastern region has developed an economy, and is significantly ahead of the central and western regions in manufacturing technology innovation and application. Therefore, manufacturing production technology plays a more prominent and significant role in pollution reduction, and technical energy conservation and emission reduction play a leading role. This point can also be proved by the fact that the influence of manufacturing technology's progress on pollution emissions from eastern, central, and western regions presents a step-down feature. The influence of manufacturing technology's progress on pollution emissions in eastern China is significant at a 1% confidence level. In comparison, in central China, it is significant at a 5% confidence level, and in western

China, it is significant at a 10% confidence level. The significant decreases, in turn, and the regional heterogeneity is obvious.

Table 7. Regression results of heterogeneity analysis.

Variables	PEI				
	Time Heterogeneity		Regional Heterogeneity		
	(13)	**(14)**	**(15)**	**(16)**	**(17)**
PCON	−0.1276978 *** (−4.95)	−0.0471361 (−0.66)	−0.1057173 * (−1.25)	−0.2922347 *** (−5.81)	−0.2961726 *** (−5.56)
PROG	−0.05729 ** (−2.45)	−0.5175846 ** (−2.54)	−1.479161 *** (−4.98)	−0.5129439 ** (−2.86)	−0.0588899 * (−1.21)
INPAT	−0.0541006 * (−0.94)	−0.2277689 (−1.04)	−0.5005879 ** (−2.37)	−0.405481 ** (−3.49)	−0.436556 *** (−5.24)
INCO	−0.0924931 * (−0.23)	−0.6305626 (−0.73)	−2.155158 ** (−2.94)	−1.13192 ** (−3.14)	−0.5746365 *** (−4.68)
EDUC	−0.2221015 ** (−2.10)	−0.3648078 (−1.20)	−0.3245671 *** (−6.57)	−0.2697252 *** (−5.59)	−0.2994751 *** (−13.56)
POPU	−0.6150911 (−1.02)	−0.5229657 (−0.25)	−3.794347 ** (−2.92)	−4.981492 * (−1.86)	−3.382123 ** (−2.31)
Enterprise individual	control	control	control	control	control
Annual time	control	control	control	control	control
Constant term	6.25885 (0.89)	7.071904 (0.44)	36.25702 *** (3.79)	48.02962 * (2.03)	−20.26683 * (−1.94)
N	279	248	187	136	204
R^2	0.0336	0.4951	0.1364	0.0179	0.6833

Note: t values are given in parentheses. ***, **, and * indicate the parameters' significance levels at the 1, 5, and 10% confidence levels, respectively.

5.5. Robustness Test

To test the robustness of the mediating effect of manufacturing technology's progress in the process of environmental regulation affecting pollution emission, given the availability and completeness of data, this paper adopts the variable replacement method to test and analyze the robustness based on the heterogeneity analysis. They consider that the explained variable chosen in this paper is sulfur dioxide emissions from industrial production. Therefore, this paper changes the definition of the environmental regulation variable to "proportion of completed investment of waste gas treatment projects in industrial added value", and makes the matching degree of the two variables of "environmental regulation" and "pollution emission" more accurate. Under the new variable definition, the mediating effect of the manufacturing industry on environmental regulation affecting the pollution emissions process is again regressed and tested, and the results are compared with the benchmark above regression results.

Column (18) of Table 8 shows the test results of the direct effect of environmental regulation on pollution emissions under the change variable, and column (19) shows the test results of the effect of environmental regulation on manufacturing technology's progress under the change variable. Column (20) shows the test results of the direct effect of environmental regulation on pollution emissions and the test results of the effect of manufacturing technology's progress on pollution emission. It can be seen that, without controlling the variable of "manufacturing technology progress", the impact of environmental regulations on pollution discharge is significant at the confidence level of 5%, and there is no significant decrease compared with the baseline regression results. The impact of environmental regulations on manufacturing technology's progress is significant at the 1%

confidence level, and there is no significant change compared with the baseline regression results. When the variable "manufacturing technology progress" is controlled, the effect of environmental regulation on pollution emissions is significant at the confidence level of 5%, which is unchanged compared with the baseline regression result. The effect of manufacturing technology's progress on pollution emissions is significant at the confidence level of 10%, and the significance decreases compared with the baseline regression results. In terms of the mediating effect of manufacturing technology's progress in the process of environmental regulation affecting pollution emission, compared with the baseline regression result, the direction of influence did not change, and the mediating effect was still significant. Therefore, the test results of the influence mechanism in this paper have strong robustness.

Table 8. Results of robustness test.

Variables	**PEI**	**PROG**	**PEI**
	(18)	**(19)**	**(20)**
PCON	−0.1660407 ** (−2.09)	0.0686756 *** (3.57)	−0.1424482 ** (−2.12)
PROG	/	/	−0.3435347 ** (−2.45)
INPAT	−0.113984 * (−1.15)	0.3594982 *** (3.88)	−0.2374842 ** (−2.68)
INCO	−0.8806816 *** (−5.10)	0.829623 *** (5.62)	−1.165686 *** (−5.10)
EDUC	−0.3283403 *** (−8.82)	0.0132272 * (1.42)	−0.3237963 *** (−8.59)
POPU	−1.481353 (−1.29)	0.6429096 (0.99)	−1.702214 (1.48)
Enterprise individual	control	control	control
Annual time	control	control	control
Constant term	20.92783 ** (2.26)	−4.129805 (−0.86)	22.34656 ** (2.45)
N	527	527	527
R^2	0.0168	0.8795	0.0001

Note: t values are given in parentheses. ***, **, and * indicate parameters' significance level at the 1, 5, and 10% confidence levels, respectively.

6. Conclusions and Policy Implications

In this paper, the provincial panel data of China from 2004 to 2020 are used to build an empirical model of mediating effect. The two-way effect regression method is adopted to conduct theoretical analysis and empirical tests on the influence of environmental regulation on pollution emissions and manufacturing technology's progress, as well as the mediating effect of manufacturing technology's progress in environmental regulation that promotes pollution reduction. This paper mainly draws the following conclusions: (1) The progress of manufacturing production technology plays a crucial role in promoting the reduction of pollution emissions. The high-quality development of the manufacturing industry and the improvement of production technology can effectively reduce pollution emissions from the source. (2) Although environmental regulation can have a significant positive impact on reducing pollution emissions, there is an intermediary effect in promoting pollution reduction by environmental regulation. The progress of manufacturing production technology is the key intermediary variable in promoting pollution reduction by environmental regulation. The manufacturing industry should increase investment in research and development, strengthen technological innovation and application, and improve research and innovation performance. (3) The test of the impact mechanism of environmental regulation on pollution reduction proves that environmental regulation can significantly positively impact pollution emissions through manufacturing technology's progress. "Environmental regulation → manufacturing technology's progress → pollution reduction" is an important path for environmental regulation to affect pollution emissions. (4) The heterogeneity test shows that, at the stage of higher development scale and technology level in the manufacturing industry, the intermediary role of manufacturing technology's progress in environmental regulation on pollution emissions is more obvious. The economic strength and manufacturing development level of eastern China is the strongest, followed by central China, and the weakest is in western China. Therefore, the role and effect of environmental regulation in promoting pollution reduction in eastern China, central China and western China declined successively. In other words, the role of environmental regulation in promoting pollution reduction increases with the improvement of manufacturing technology. After the robustness test, the above research conclusions of the text are still valid. Based on the research findings, the following policy implications can be proposed: Firstly, the government should formulate and introduce environmental regulation policies to promote the upgrade of manufacturing technology. Due to the strong negative externality of pollution emissions and the fact that the manufacturing industry is an important industry supporting the healthy development of the real economy, it is necessary for the government to scientifically and reasonably intervene in pollution emissions and the technological upgrade of the manufacturing industry; this should be implemented through market-oriented means and various policy combinations such as fiscal, financial and taxation. We should strike a balance between environmental protection, technological innovation, and economic growth.

Secondly, the government should encourage and support manufacturing enterprises to innovate, and apply energy conservation and emission reduction technologies. As the main force behind technological innovation, manufacturing enterprises have made great contributions to technological progress and have become the basic force behind promoting pollution reduction through technological innovation. Technological innovation in manufacturing enterprises is not only an internal requirement to enhance the competitiveness of enterprises, but it can also effectively enhance the efficiency of manufacturing enterprises in utilizing production resources, reduce the dependence on resource factors, and reduce the pressure on environmental carrying capacity. Therefore, it is necessary to increase technological innovation support for manufacturing enterprises, accelerate the development, innovation, and application of energy-saving and emission-reduction technologies in manufacturing enterprises, improve the production process, apply advanced production technology, and take the road of upgrading and developing technology–innovation-oriented manufacturing industry.

Thirdly, the government should develop and expand high-tech manufacturing vigorously. Although the manufacturing industry is the main source of production pollution, it is also an irreplaceable agency through which to reduce pollution production and emissions. Only by constantly promoting the development of the manufacturing industry can the endogenous driving force behind pollution reduction be continuously consolidated and improved. Therefore, we should continue to increase the proportion of high-tech manufacturing, promote the upgrade of the manufacturing industry, optimize the industrial structure of the manufacturing industry, and extensively develop and apply artificial intelligence, industrial Internet and other cutting-edge technologies to transform and upgrade the manufacturing industry and foster new forms of manufacturing. In the process of the technological upgrade and sustainable development of the manufacturing industry, advanced production technology and pollution control mechanisms are constantly cultivated; these fully magnifies the policy effect of environmental regulation on the promotion of pollution reduction.

7. Limitations and Recommendation for Future Studies

Firstly, the study did not use the data of major countries in the world for the empirical tests, and the data diversity in terms of the country is not strong enough. Therefore, future studies should focus on collecting data from major industrial countries worldwide, and conduct a further empirical test on the impact and role of manufacturing production technology's progress on environmental protection and pollution reduction.

Secondly, this study used proxy variables of environmental regulation from the perspective of pollution control input. However, the proxy variables of environmental regulation have not been constructed from the perspective of pollution control and corresponding empirical tests. Due to the difference between the investment in pollution control and the effect of pollution control, the accuracy of proxy variables of environmental regulation is not particularly high, and there is still room for improvement. Therefore, future studies must focus on proxy variables of environmental regulation to estimate the effect of pollution control, improve the construction method of environmental regulation indicators, enhance the comprehensiveness and accuracy of proxy variables of environmental regulation, and strengthen the robustness test of the empirical study.

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Abbreviations

AI	Artificial Intelligence
GDP	Gross Domestic Product
R&D	Research and Development

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