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Impact of Voluntary Environmental Regulation on Green Technological Innovation: Evidence From Chinese Manufacturing Enterprises

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Can voluntary environmental regulation play a major role in the transformation of traditional environmental regulation; undertake the task of improving the flexibility, autonomy, and effectiveness of environmental regulation; and promote green technology innovation of enterprises? This study uses the propensity score matching and difference-in-differences (PSM-DID) model to analyze the net effect and heterogeneity of voluntary environmental regulation on green technology innovation, and further explores the impact mechanism of voluntary environmental regulation on green technology innovation from three perspectives: government subsidies, public support, and external enterprise cooperation. The results show that voluntary environmental regulation has a significant positive effect on green technology innovation regardless of time, industry, and regional factors. The implementation of voluntary environmental regulation promotes the green patent authorization of enterprises by 15.12–17.59%. In addition, voluntary environmental regulation also shows industry heterogeneity, scale heterogeneity, and ownership heterogeneity for green technology innovation, and it emphasizes the promotion effect on enterprises in mild pollution industries, large-scale enterprises, and private enterprises. Furthermore, the implementation of voluntary environmental regulation will have a positive impact on green technology innovation by curbing public support and expanding cooperation with external enterprises.

Keywords: voluntary environmental regulation, green technology innovation, government subsidies, public support, enterprise cooperation

1 INTRODUCTION

Environmental problems have consistently been the main obstacles to achieving high-quality economic development and improving people's quality of life. Recently, China has devoted increasing attention to ecological environmental protection (Wu et al., 2021). In addition, the successive promulgation and implementation of the Environmental Protection Law (2015), the Environmental Protection Tax Law (2018), and the Cleaner Production Promotion Law of the People's Republic of China (2019) have further strengthened the attention of enterprises to environmental protection. The 14th Five-Year Plan in 2021 also points out that enterprises should be encouraged to increase investment in research and development, increase the disclosure of environmental protection information, and guide social organizations and the public to participate in environmental governance. As the main force to create economy, enterprises serve as the main body of environmental pollution and assume responsibility for protecting the environment (Wu et al., 2022). Voluntary environmental regulation, as a way for enterprises to fulfill their corporate social responsibility, differs from the traditional environmental regulation, which gives enterprises autonomy and can stimulate enterprises to innovate from inside to outside (Qin and Sun., 2020). However, relatively few studies have explored voluntary environmental regulation. As an important pillar of the national economy, the traditional economic development in the manufacturing industry is dominated by extensive scale expansion and has brought huge resource and environmental constraints to China, and the weak originality and high imitation of its technology have also caused problems such as large energy consumption and low energy utilization. By the end of 2020, the ratio of manufacturing energy consumption to China's total energy consumption is 55.1%, while the proportion of manufacturing industry to GDP is only 26.18%. With the increasingly fierce conflict between economic development, energy consumption, and environmental pollution, it is necessary to pay attention to the green technology innovation of the manufacturing industry.

In summary, an in-depth discussion of the paths and mechanisms for voluntary environmental regulations to affect the green innovation of enterprises will help guide enterprises to fulfill their social responsibilities, give full play to the subjective initiative of enterprises, stimulate enterprises to implement green innovation from the internal, and achieve high-quality economic development. Therefore, this paper needs to answer two questions: 1) whether voluntary environmental regulations have an effect on the green technology innovation of manufacturing enterprises; 2) if the effect exists, how it works at micro-level. This paper uses the propensity score matching and difference-in-differences (PSM-DID) model to analyze the impact of voluntary environmental regulation on the green technology innovation of Chinese manufacturing enterprises and further classifies the manufacturing enterprises in order to examine the industry heterogeneity effect, scale heterogeneity effect, and ownership heterogeneity effect of voluntary environmental regulation on the green technology innovation of manufacturing enterprises. Finally, the mechanism analysis model is constructed to analyze the mediating effect of voluntary environmental regulation on the green technology innovation of enterprises by the government, the public, and external enterprises.

The marginal contribution of this study is mainly manifest in three aspects. Firstly, we obtained data on green technology innovation patents for the listed enterprises based on the comparison between the Green List of the International Patent Classification launched by WIPO (World Intellectual Property Organization) with those of the State Intellectual Property Office, which compensated for the limitation of using utility model patents solely as a measure of the level of green technology innovation of enterprises. Secondly, this paper further examines the heterogeneous response of green technology innovation to voluntary environmental regulation using three aspects: industry heterogeneity, scale heterogeneity, and ownership heterogeneity. Finally, based on the relationship between enterprises and the government, the public, and external enterprises, we further discuss the government subsidy effect mechanism, public support effect mechanism, and enterprise cooperation effect mechanism of implementing voluntary environmental regulation on enterprise green technology innovation and provide a new explanation for enterprise green technology innovation.

The structure of this study is as follows. **Section 2** summarizes the existing research advances and their limitations. **Section 3** introduces the construction of the PSM-DID model and the mechanism analysis model. **Section 4** examines the industry heterogeneity effect, scale heterogeneity effect, ownership heterogeneity effect, and intermediary effect of voluntary environmental regulation on the green technology innovation of manufacturing enterprises. **Section 5** draws conclusions and policy implications based on research findings.

2 LITERATURE REVIEW AND THEORETICAL HYPOTHESES

2.1 The Effect of Voluntary Environmental Regulation on Green Technology Innovation

Environmental regulation tools are mainly divided into three types: mandatory, market-based, and voluntary (Ren et al., 2018a). Previous empirical literature presents different conclusions about whether environmental regulation can induce green technology innovation, and some scholars believe that environmental regulation will have an inhibitory effect on the technological innovation of enterprises (Greenstone et al., 2012). Some scholars believe that well-designed environmental regulations can effectively promote green technology innovation (Ley et al., 2016; Qiu et al., 2020). Others argue that environmental regulation does not significantly promote the technological progress of enterprises (Eiadat et al., 2008), but existing studies have paid less attention to voluntary environmental regulation.

Voluntary environmental regulation is an agreement, commitment, or plan aimed at protecting the environment. It is based on the voluntary participation of enterprises, advocated by industry associations, enterprises themselves, or third-party certification bodies without specific mandatory binding (Qin and Sun, 2020). Unlike command-and-control environmental regulation, the core idea of voluntary environmental regulation is to create incentives for enterprises to spontaneously provide environmental public goods (Pan et al., 2020). Most studies within the available literature have validated a positive correlation between voluntary environmental regulation and corporate innovation (Lim and Prakash, 2014; Ren et al., 2018b; He and Shen, 2019; Bu et al., 2020). Some studies also suggest that voluntary environmental regulation can boost the profits of large companies but has no significant impact on corporate innovation (Long and Wan, 2017). In addition, existing studies mostly use R&D expenditures, the number of patent applications, the number of invention patent applications, and the construction of knowledge stock indicators to measure green technology innovation (Du and Li, 2019; Ouyang et al., 2020; Sun et al., 2021). However, the number of green patents obtained by enterprises, as an indicator of green technology innovation output, can better reflect the level of green innovation of enterprises.

At present, the voluntary environmental regulations that are widely practiced in China only are the ISO14001 environmental management system and the "responsible care" system of the chemical industry. By the end of 2020, only 636 chemical companies in China had signed the Responsible Care Global Charter. In addition, most of the enterprises that have joined the Charter of Care for Responsibilities do not fully follow the normative requirements of the Guidelines for the Implementation of Care for Responsibilities to formulate target plans, implement self-assessments, and enforce improvement measures (Pan et al., 2020). To address this situation, this study selects ISO14001 environmental management system certification data to measure the voluntary environmental regulation behavior of enterprises and proposes hypothesis 1.

H1: The implementation of voluntary environmental regulations can help promote green technology innovation in enterprises.

2.2 The Impact Mechanism of Voluntary Environmental Regulation on Green Technology Innovation

So how can voluntary environmental regulations promote green technology innovation in enterprises? Research has discussed the relationship between government, public, external enterprise behavior, and enterprise innovation (Shi et al., 2020; Fang et al., 2021; Jiang et al., 2021). From a government perspective, the implementation of voluntary environmental regulations will help enterprises labelled as approved by the government, giving them the opportunity to receive support from relevant government policies, which will further incentivize companies to innovate with green technology. Since green technology innovation has the negative externality of environmental resource utilization and the positive externality of technological innovation, the negative externality of environmental resource utilization requires environmental regulation to play a corrective role, and the positive externality of technological innovation requires the guidance and support of the government through financial policies (Liu et al., 2020). Hille et al. (2020) find that, while the importance of policy instruments varies from technology to technology, their impact on innovation is very similar. A more comprehensive renewable energy support policy portfolio increases the patent applications for solar and wind-related technologies. From the perspective of the public, the increase in public environmental awareness will cause certain pressure on the reputation of enterprises and the sale of products, affecting the technological innovation of manufacturing enterprises (Czarnitzki et al., 2020). Jiang et al. (2021) found

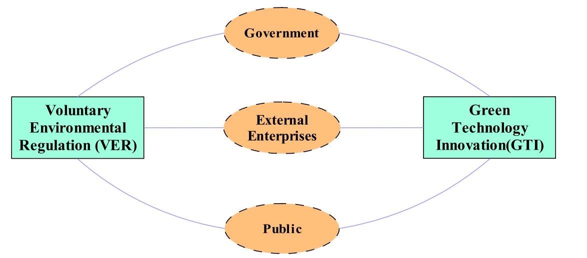

FIGURE 1 | Theoretical model framework.

that companies tend to use public relations to respond to the public's demand for environmental protection. In the case of limited resources, public relations expenditure will squeeze enterprises' investment in green technology innovation. The enhancement of environmental awareness has prompted the public's consumption demand to gradually shift to environmentally friendly products, and it has also increased its requirements for the practical legitimacy of corporate products (Zhu et al., 2013). This may further lead enterprises to implement voluntary environmental regulation in order to obtain public identity; that is, they will carry out ISO14001 certification in order to obtain the recognition of practical legitimacy of products, rather than truly green technology innovation. Pan et al. (2020) argues that some companies are under pressure from downstream multinational green supply chains to send environmentally friendly signals to consumers through voluntary environmental regulation compliance. From the perspective of cooperation with external enterprises, enterprises implementing voluntary environmental regulation will send signals of environmental commitment to external partners so as to obtain abundant resources for green innovation. Communication and cooperation with external enterprises can help enterprises obtain complementary resources that they do not have and help enterprises integrate internal and external resources for innovation (Zhou et al., 2018). Synergies with organizations in different fields help to accelerate technological breakthroughs, eliminate technological bottlenecks in the enterprise innovation ecosystem, and accelerate the pace of enterprise innovation (Masucci et al., 2020). In addition, sharing risks and costs with partner enterprises reduces the risk and cost of responding to environmental regulation by shortening the innovation cycle and reducing innovation risks (Aigbavboa and Mbohwa, 2020).

To sum up, government policies, public awareness of environmental protection, and external cooperation of enterprises have not only created the demand for voluntary environmental regulation, but also further promoted the positive relationship between voluntary environmental regulation of enterprises and green technology innovation. However, existing studies have mostly studied the impact of environmental regulation on technological innovation from the level of stakeholders such as government and consumers, and the level of partners (Ouyang et al., 2020; Sun et al., 2021; Yuan and Cao, 2022). This paper is more targeted to study the impact of government policies, public awareness of environmental protection, and external cooperation of enterprises on the impact of voluntary environmental regulation on enterprise green technology innovation. Based on this, the following three theoretical hypotheses are proposed (**Figure 1**).

H2: The introduction of government incentive policy will effectively guide the direction of green technology innovation and encourage enterprises to carry out green technology innovation.

H3: Increased public awareness of environmental protection will lead to the implementation of voluntary environmental regulation for enterprises to establish an environmentally friendly image and hinder enterprises' investment in green technology innovation.

H4: The expansion of cooperation with external enterprises will help enterprises obtain complementary resources and promote green technology innovation.

3 MATERIALS AND METHODS

3.1 Identification Model and Strategy

3.1.1 Baseline Model Setting

First of all, enterprises with a high level of green innovation can be more inclined to carry out ISO14001 standard certification. Therefore, it is a self-selection issue whether enterprises implement voluntary environmental regulation. This paper overcomes the possible interference of this problem by performing Propensity Score Matching (PSM). The return on assets (ROA), board independence (Independence), enterprise age (Age), and quality management system (ISO9000) are selected as matching variables. The empirical test object of this paper is the sample obtained after PSM. Since the sample enterprises in the treatment group and the control group have no significant differences in age, profitability, and governance level except for the difference in the implementation of voluntary environmental regulation, the difference-in-differences (DID) test adopted later is more effective and reliable. Secondly, the implementation of voluntary environmental regulation is in different years, which means that the same company can be both a treatment group (after the implementation of voluntary environmental regulation) and a control group (before the implementation of voluntary environmental regulation), which can alleviate the endogenous problems caused by sample selection errors to some extent. In summary, PSM can solve the problem of sample selectivity deviation, but it cannot overcome the endogenous problem. The double-difference method has some complementarity. Although it cannot solve the problem of sample deviation, it can effectively overcome the endogenous problem. Therefore, this paper refers to the research of Quan et al. (2020), constructs two virtual variables voluntary participation in environmental regulation (VER) and *POST*, and establishes the following PSM-DID model to test the impact of voluntary environmental regulation on green technology innovation.

$$Lnpat = \alpha_0 + \alpha_1 VER + \alpha_2 VER \cdot POST + \alpha_3 \text{Control} + \varepsilon \quad (1)$$

3.1.2 Identification Model for Effect Mechanism

Theoretical research shows that the influence path of voluntary environmental regulation on enterprise green innovation differs, which means that the government, the public, and external enterprises have different degrees of influence on the relationship between voluntary environmental regulation and enterprise green innovation. As such, this study constructs the following analysis model to test the moderating effect of government subsidies, public support, and external enterprise cooperation between the two. The details are as follows:

$$L\text{npat}_{it} = \alpha_1 + \beta_1 VER_{it} + \lambda_1 \text{Control}_{it} + \varepsilon_{it} \quad (2)$$

$$L\text{npat}_{it} = \alpha_2 + \beta_2 VER_{it} + \beta_3 \text{Subsidy} + \beta_4 VER_{it} \cdot \text{Subsidy} + \lambda_2 \text{Control}_{it} + \varepsilon_{it} \quad (3)$$

$$L\text{npat}_{it} = \alpha_3 + \beta_5 VER_{it} + \beta_6 P\text{ublic} + \beta_7 VER_{it} \cdot P\text{ublic} + \lambda_3 C\text{ontrol}_{it} + \varepsilon_{it} \quad (4)$$

$$L\text{npat}_{it} = \alpha_4 + \beta_8 VER_{it} + \beta_9 \text{Cooperation} + \beta_{10} VER_{it} \cdot \text{Cooperation} + \lambda_4 \text{Control}_{it} + \varepsilon_{it} \quad (5)$$

In the formula, *i* represents the enterprise; *t* represents year; Lnpat represents green technology innovation; *VER* represents enterprises to implement voluntary environmental regulation; and *Subsidy*, *Public*, and *Cooperation* represent government subsidies, public support, and external cooperation, respectively. *Control* is the control variable; coefficient α represents intercept term; β represents the impact of voluntary environmental regulation on green innovation, λ represents the estimated coefficient of each control variable; and ε is a random disturbance.

3.2 Variable Description and Data Source

In order to explore the relationship between voluntary environmental regulation and enterprise green technology innovation, this paper takes Shanghai and Shenzhen A-share manufacturing listed companies from 2015 to 2018 as research samples.

The dependent variable is green technology innovation, which is represented by Green Patent (Lnpat1/Lnpat2). According to the comparison between the international patent classification green list launched by WIPO and the State Intellectual Property Office, the patent data of green technology innovation of listed companies are obtained, which makes up for the limitation of using utility model patents as a measure of the level of green technology innovation of enterprises. In addition, due to the large lag of enterprise patent licensing, the number of green patent licensing with a lag of 1 year is adopted; that is, the logarithm of the number of green patent licensing in the t+first year plus one is taken.

The independent variable is VER. According to the ISO14001 environmental management system certification data, this year through the ISO14001 certification enterprise assignment is one and is 0 otherwise. POST is the virtual variable after the implementation of voluntary environmental regulation, and the year after the implementation of voluntary environmental regulation (including the year) is assigned to 1, otherwise 0.

The moderating variables include government support (Government), public environmental awareness (Public), and external cooperation (Cooperation). Government support is expressed by government environmental protection subsidies, drawing on Tang and Li (2013), the classification of environmental investment content to determine the amount of government environmental subsidies listed companies currently received, and logarithmic processing. The public's environmental awareness is expressed by the growth rate of sales and the public votes with purchasing power, showing recognition of the practical legitimacy of products. The higher the public support of enterprises and the steady growth of sales, the easier it is for enterprises to borrow funds from third parties to increase their capital, and the more likely it is to increase investment in green technology innovation and open up the market (Darya and Maesaroh, 2016). With reference to the method of Laursen and Salter (2014), the external cooperation of enterprises is measured by the number of partners jointly applying for patents. The greater the number of partners, the greater the degree of cooperation.

This paper selects Return on Assets (*ROA*), Z index (*Z*), Ratio of Independent Director (*Independence*), Cash Ratio (*Cash*), Enterprise Scale (*Scale*), Age, State-owned enterprises (*SOE*), Debt-to-Asset Ratio (*Debt*), Operating Income (*Income*) and Period expense ratio (*Expense*) as control variables. *ROA* is expressed by the ratio of net profit to average total assets to measure the profitability of the company. *Z* is expressed by the ratio of the largest shareholder to the second largest shareholder to measure the degree of equity balance. *Independent* is the proportion of independent directors in all directors, which is used to measure the level of corporate governance. *Cash* is represented by the ratio of total current assets to total current liabilities, which is used to measure the ability of current assets of enterprises to become cash for debt repayment before the short-term debt expires. *Scale* represents company size, which is measured by the total assets of the year. *Age* represents the age of the company. For measures of *SOE*, the non-state-owned enterprises are assigned 0 and the state-owned enterprises are assigned 1. *Debt* is expressed by the ratio of total corporate liabilities to total assets to measure the asset-liability ratio. *Income* is the year's operating income. *Expense* is the ratio of management, sales, and financial management costs to operating income in the year.

The research objects of this paper are Shanghai and Shenzhen A-share manufacturing listed companies from 2012 to2018[1]. In order to ensure the effectiveness and operability of the data, a series of screenings are carried out: ST, *ST, and PT[2] enterprises; the sample with missing variable data participated in regression. After the above processing, the initial sample of this paper comprised 7,336 samples, a total of 1,048 listed companies, including the implementation of voluntary environmental regulation of listed companies, the total was 588. The government environmental protection subsidies data in this paper are from the annual report of enterprises and the corporate social responsibility report, and the rest of the data are from CSMAR (http://cndata1.csmar.com). The statistic description of treatment groups and control groups are detailed in **Supplementary Appendix Table S2**.

4 RESULTS AND DISCUSSION

4.1 Propensity Score Matching

4.1.1 PSM Result

In general, return on assets (ROA), board independence (Independence), enterprise age (Age), and quality management system (ISO9000) will affect the impact of ISO14001 standard certification on the green innovation performance of enterprises (Bourke and Roper, 2017; Li et al., 2017; Bouncken et al., 2021; Sun et al., 2021). The investment cycle of green innovation is long. Enterprises with better financial performance often have more human, material, and financial resources, and they can invest in green innovation for an extended period. The higher the return on assets of enterprises, the more likely green innovation is. The stronger the independence of the board of directors, the stronger the social responsibility orientation toward proactive green technology innovation. Mature enterprises have rich production and management experience and good R&D foundation, which helps enterprises to carry out green technology innovation, and enterprises with ISO9000 certification are more likely to apply for ISO14001 certification. Therefore, the four indicators are selected as observable variables, and the propensity score is calculated by logit regression. Then the PSM is carried out, and the treatment group and the control group in the sample are matched reasonably. Finally, the ATT value is calculated according to the matched sample.

According to the four matching variables, logit regression is carried out on the grouping variables to determine whether to implement voluntary environmental regulation. The control group is selected and matched by one-to-four matching method in the caliper, and the annual observation value of 7,323 enterprises is finally obtained. **Table 1** reports the treatment effect of ISO14001 certification enterprises. Whether before or after matching, the average green innovation performance of enterprises certified by ISO14001 standard is higher than that of enterprises not certified by the ISO14001 standard. From the matching results, the average green innovation performance of enterprises certified by ISO14001 is 0.48, enterprises not certified by ISO14001 is 0.31, and the ATT value is 0.18. The statistics of *t*-test of those values are all greater than 2.58, which shows that voluntary environmental regulation can promote green innovation of enterprises.

[1]The reason the sample data from 2012 to 2018 are selected is that the green technology innovation data are only updated to 2019, and the number of green patent authorizations that lag 1 year is used.

[2]Stocks with "ST" or "*ST" are traded on risk alert board. Stocks carrying "ST" (special treatment) tag suffer losses for two consecutive years or more. Stocks carrying "*ST" tag enter delisting procedures. With "PT" (Particular Transfer), stocks suffer losses for 3 years or more, and are halted the listing.

TABLE 1 | Tendency score matching results.

Variable	Sample	Treated	Controls	Difference	S.E.	T-Stat
Lnpat	Unmatched	0.4786	0.3352	0.1433	0.0188	7.59
	ATT	0.4786	0.3014	0.1772	0.0228	7.75
	ATU	0.3348	0.4809	0.1460		
	ATE			0.1635		

TABLE 2 | PSM Equilibrium Test (1).

Variable	Unmatched	Mean		%Reduct		*t*-test	
	Matched	Treated	Control	%Bias	|bias|	t	p>|t|
IS O 9001	U	0.4060	0.0997	75.30		31.14	0.0000
	M	0.4054	0.4051	0.10	99.90	0.02	0.9820
LnAge	U	3.1201	3.0990	9.40		3.99	0.0000
	M	3.1200	3.1192	0.30	96.50	0.15	0.8810
ROA	U	0.0402	0.0367	4.90		2.11	0.0350
	M	0.0404	0.0408	–0.70	86.80	–0.32	0.7500
Independence	U	0.3720	0.3765	–8.00		–3.42	0.0010
	M	0.3720	0.3728	–1.40	83.00	–0.63	0.5270

TABLE 3 | PSM equilibrium test (2).

Sample	Ps R2	LR chi2	p > chi2	MeanBias	MedBias	B	R	%Var
Unmatched	0.095	960.270	0.000	24.400	8.700	76.5*	2.55*	33
Matched	0.000	2.790	0.594	1.300	0.900	3.700	0.780	33

*Note: * if B>25%, R outside [0.5; 2].*

4.1.2 Balanced Test

The balance test examines whether the choice of observable variables and methods is appropriate. **Table 2** is the result of matching balance test. Before matching, except for *LnAge*, the treatment group and control group showed significant difference ($p < 0.01$). After matching, the absolute values of standard deviation of variables are not more than 2%, and the results of *t* test are not obvious, indicating that there is no significant systematic difference between the treatment group and the control group, and the selection of observable variables and methods is appropriate. In addition to whether the ISO14001 standard is certified, the matched treatment group and the control group have similar characteristics. If there are differences in green technology innovation between them, it must be caused by the implementation of voluntary environmental regulation. In addition, this paper also examines the pseudo-R^2 and joint statistical significance of covariate propensity score. As **Table 3** shows, before matching, the pseudo-R^2 value is 0.095, and the *p*-value of LR test is close to 0. After matching, the pseudo-R^2 value is close to 0, and the *p*-value of LR test is 0.594. This indicates that the matching has successfully eliminated the observable system differences between the treatment group and the control group. The above statistical test proves the validity of the matching results. It can be considered that the matching variables and methods used in this paper are suitable. The samples obtained after matching conform to the random principle of sample processing to some extent, which improves the reliability of the empirical results in this paper.

4.2 Baseline Regression

The double-difference regression between voluntary environmental regulation and green technology innovation is carried out with 7,323 observations obtained by PSM. **Table 4** reports the results of DID regression. Models 1) and 2) control the time, industry, and regional factors, while models 3) and 4) are not controlled. According to the empirical test results, the VER × POST coefficient is significantly positive at the 5% level. Combined with descriptive statistics, under the control of time, industry, and regional factors, the green patent authorization (Lnpat1) increased by 17.59% after the implementation of voluntary environmental regulation, and the green patent authorization (Lnpat2) increased by 16.64% in the delayed phase. Without control, lnpat1 and lnpat2 increased by 16.26 and 15.12%, respectively. This shows that, under the control of other influencing factors, regardless of whether or not the time, industry, and regional factors are controlled, the green innovation output of enterprises implementing voluntary environmental regulation is higher, and the implementation of voluntary environmental regulation by enterprises helps to

TABLE 4 | Baseline regression results.

	Lnpat1	Lnpat2	Lnpat1	Lnpat2
	(1)	(2)	(3)	(4)
VER	0.0647*** (0.0212)<	0.0559*** (0.0216)	0.0831*** (0.0216)	0.0781*** (0.0221)<
VER×POST	0.0731*** (0.0277)	0.0720** (0.0280)	0.0676** (0.0269)	0.0654** (0.0276)
Controls	Yes	Yes	Yes	Yes
Year	Yes	Yes	No	No
Industry	Yes	Yes	No	No
Area	Yes	Yes	No	No
Pseudo R^2	0.1991	0.1997	0.1288	0.1262
Obs	7,323	7,323	7,323	7,323

*Note: ***p < 0.01, **p < 0.05, *p < 0.1, robust standard errors in parentheses (the same below).*

improve their green technology innovation ability. Therefore, H1 of this study is verified[3].

4.3 Heterogeneity Analysis

4.3.1 Industry Heterogeneity

Different industries with different pollution intensity have different sensitivity to environmental regulation, resulting in different incentive effects from environmental regulation on enterprise technological innovation (Ren et al., 2016; Feng and Chen, 2018). In order to further examine the industry heterogeneity effect of voluntary environmental regulation on enterprise green technology innovation, this paper refers to the classification method of Fu and Li (2010) and Ren et al. (2016) and divides 30 sub-industries of China's manufacturing industry, which covered in the samples, into severe pollution, moderate pollution, and mild pollution according to the pollution emission intensity (the classification results are shown in **Supplementary Appendix Table S1**)[4]. Specific classification methods are as follows:

(1) Calculation of pollutant emissions per unit output value of various industries:

$$UP_{itj} = \frac{P_{itj}}{TV_{it}} \tag{6}$$

Where i represents industry, t is the year, j is the pollutant category, $j = 1, 2, 3$ is the emissions of wastewater, waste gas, and solid waste respectively, P_{itj} is the emissions of the j pollutant in industry i in year t, TV_{it} is the total industrial output value of industry i in year t.

(2) Dimensionless individual indicators:

$$UP'_{itj} = \frac{\left(UP_{itj} - \min\left(UP_{tj}\right)\right)}{\left(\max\left(UP_{tj}\right) - \min\left(UP_{tj}\right)\right)} \tag{7}$$

Where $\max(UP_{tj})$ and $\min(UP_{tj})$ are the maximum and minimum emissions of pollutants j per unit output value in all manufacturing industries in the current year, respectively.

(3) Calculation of pollution emission intensity index in different industries over the Year:

$$PL_{it} = \frac{1}{3}\sum_{j=1}^{3} UP'_{itj} \tag{8}$$

(4) The pollution emission intensity index of each industry from 2012 to 2018 was averaged to obtain the final pollution emission intensity of each industry:

$$\overline{UP_{\mathrm{ij}}} = \frac{\left(UP_{\mathrm{ij}} - \min\left(UP_{\mathrm{j}}\right)\right)}{\left(\max\left(UP_{\mathrm{j}}\right) - \min\left(UP_{\mathrm{j}}\right)\right)} \tag{9}$$

Where $\max(UP_j)$ and $\min(UP_j)$ in all manufacturing industries, and the maximum and minimum emissions of pollutants j per unit output value are standardized values.

(5) The pollution emission index per unit output value of each industry is summarized by equal weight addition and average method, and the industry pollution intensity index is finally obtained PL_i:

$$PL_{\mathrm{i}} = \frac{1}{3}\sum_{\mathrm{j=1}}^{3} \overline{UP_{\mathrm{ij}}} \tag{10}$$

Figure 2 reports the impact of voluntary environmental regulation on green technology innovation of enterprises in mild, moderate, and severe pollution industries. Among them, the sample group of enterprises in mild pollution industries is significantly positive at the 1% level, regardless of whether they control the time and region and whether they use the green patent authorization of the postponed period, and the marginal effect is 0.14–0.16. The sample group of enterprises in other pollution industries is not significantly, that is, only when enterprises in mild pollution industries implement voluntary environmental

[3]18.98, 18.08, 16.36 and 15.05% are obtained by dividing the coefficients of PDRC×POST in **Table 4** by the descriptive statistical mean of explained variables lnPat1 and lnPat2 by 0.4156 and 0.4326, respectively.

[4]Among them, chemical oxygen demand and ammonia nitrogen emissions are used as indicators for wastewater discharge; emissions of industrial sulfur dioxide, industrial nitrogen oxides, and industrial particulate matter are used as indicators of emissions; solid waste emissions use the production of general industrial solid waste and hazardous waste as indicators, and data are from the ' China Environmental Statistics Yearbook.

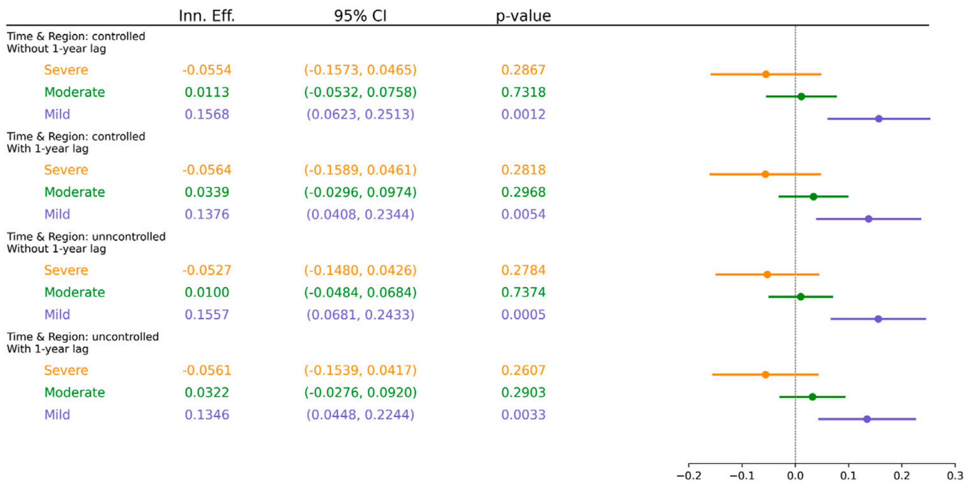

FIGURE 2 | Industry heterogeneity regression results.

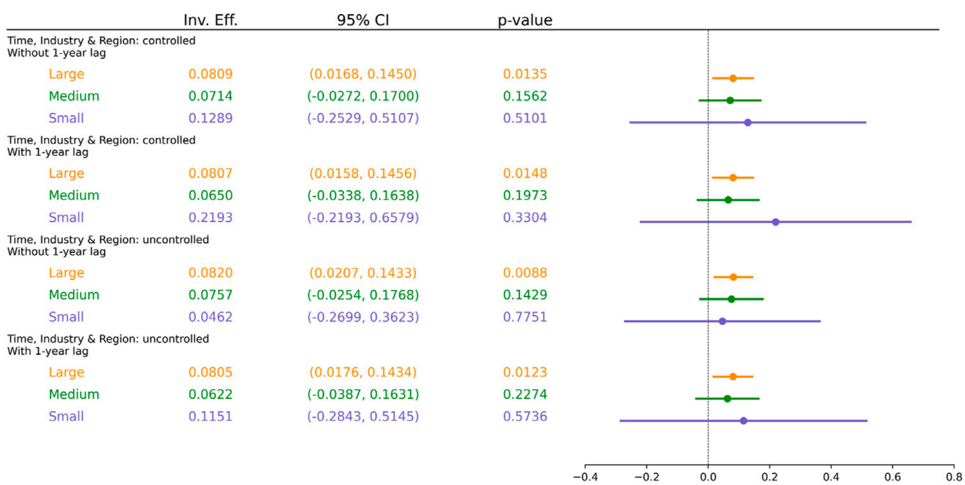

FIGURE 3 | Enterprise scale heterogeneity regression results.

regulation can they promote green technology innovation. Compared with enterprises in mild-polluting industries, enterprises in heavy polluting industries need higher intensity of environmental regulation to promote product innovation (Fang et al., 2021). Although the intensity of voluntary environmental regulation is not sufficient to promote green technology innovation in heavy polluting enterprises, it still has a positive impact on enterprises in mild-polluting industries, which further verifies H1.

4.3.2. Enterprise Scale Heterogeneity

Enterprise scale is the key internal factor to determine the technological innovation of enterprises (Lee and Xia, 2006). There is a certain difference in technological innovation ability between enterprises with different scales. Large-scale enterprises have more resources and a higher investment ability in technological innovation, which will influence the effect of voluntary environmental regulation on green technology innovation to a certain extent. The technological innovation ability of large-scale enterprises is generally relatively higher (Li et al., 2019). In order to further investigate the scale heterogeneity effect of voluntary environmental regulation on enterprises green technology innovation, this paper divides enterprises into large enterprises, medium enterprises, and small enterprises according to the Small and Medium-sized Enterprise Planning Standard, promulgated in2011[5].

[5]We define enterprises with more than 1,000 employees or an operating income of more than 400 million yuan as large enterprises; enterprises with more than 300 employees or an operating income of more than 200 million yuan as medium-sized enterprises; enterprises with more than 20 employees or an operating income of more than three million yuan as small enterprises.

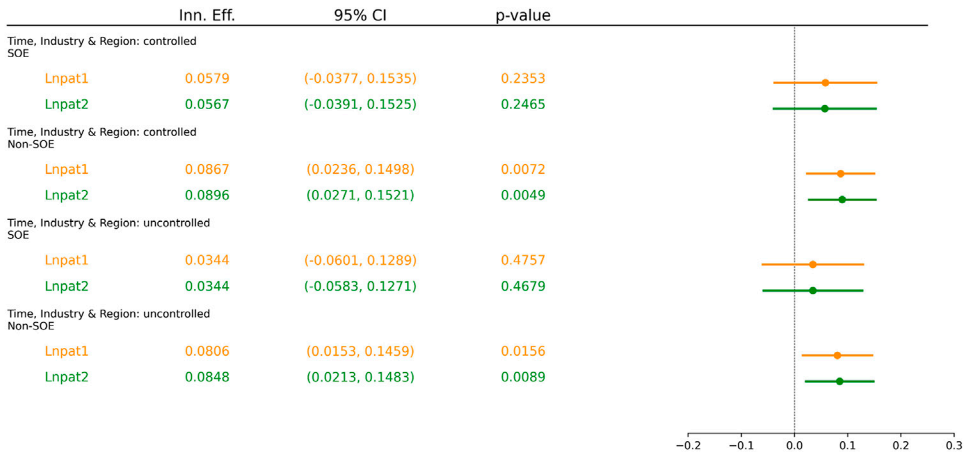

FIGURE 4 | Ownership heterogeneity regression results.

Figure 3 reports the impact of voluntary environmental regulation on green technology innovation of small, medium, and large enterprises. Although the number of samples of large, medium, and small enterprises is inconsistent, the proportion of voluntary environmental regulation is relatively close, which is 17, 22, and 30% respectively. Among them, the sample group of large enterprises was significantly positive at the 1 and 5% levels, and its marginal impact was 0.0805–0.0820, while the sample group of small- and medium-sized enterprises was not. That is, the implementation of voluntary environmental regulation by large-scale enterprises is conducive to promoting green technology innovation. In general, the larger the enterprise scale, the more intensive the enterprise innovation activities are (Shi et al., 2018; Tang et al., 2020). Compared with small- and medium-sized enterprises, large enterprises have stronger financial strength and more innovation resources, so they have stronger advantages and better conditions for green technology innovation.

4.3.3 Ownership Heterogeneity

Because innovation has a spillover effect and state-owned enterprises can alleviate market failure caused by an incomplete monopoly of knowledge production through their own or government intervention, it is generally considered that state-owned enterprises are more likely to innovate (Bai et al., 2019; Wang and Jiang, 2021). Therefore, this paper divides enterprises into state-owned enterprises and non-state-owned enterprises, and further examines the ownership heterogeneity effect of voluntary environmental regulation on enterprise green technology innovation.

Figure 4 reports the impact of voluntary environmental regulation on green technology innovation of state-owned and non-state-owned enterprises. Different from the existing research, the sample groups of non-state-owned enterprises are significantly at the 1 and 5% levels. No matter whether the green patent authorization is delayed for one period, the marginal effects are not significantly different. When the time, industry, and region are controlled, the marginal effects are 0.09, and when the time, industry, and region are not controlled, the marginal effects are 0.08. However, the sample groups of state-owned enterprises are not significantly; that is, the implementation of voluntary environmental regulation by private enterprises is more conducive to promoting their green technological innovation process. This may be because, compared with private enterprises, executives of state-owned enterprises are less stressed by innovation from market stakeholders, and their professional goals are generally political promotion rather than corporate performance. At the same time, because they cannot legally own corporate ownership, they are more likely to produce innovation inertia, so even if voluntary environmental regulation is implemented, there will be no excessive investment in green technology innovation. Private enterprises pay more attention to the maximization of enterprise profit and enterprise value. Their goal orientation is basically consistent with R&D innovation activities, and they are more willing to continue to invest in green technology innovation.

4.4 Mechanism Analysis

4.4.1 Government Subsidy Effect

Theoretical research shows that the positive impact of voluntary environmental regulation on government subsidies further influences its green technology innovation effect. Because green technology innovation has the characteristics of positive externalities of innovation knowledge and negative externalities of environment, enterprises cannot obtain enough innovation benefits, so government subsidies are an important vehicle to make up for the double externalities of green technology innovation and promote enterprises to carry out green technology innovation (Bai et al., 2019). Government subsidies entice enterprises to increase R and D investment and promote green technology innovation (Becker, 2015).

In order to verify the positive impact of voluntary environmental regulation on government subsidy support, we use the mediating effect model to empirically test the government subsidy effect of voluntary environmental regulation on green technological innovation. In the benchmark regression equation,

TABLE 5 | Test of action mechanism (1).

	Lnpat1	Lnpat2	Lnpat1	Lnpat2	Lnpat1	Lnpat2	Lnpat1	Lnpat2	Lnpat1	Lnpat2	Lnpat1	Lnpat2
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Goverment	0.0074** (2.2546)	0.0068** (2.0264)					0.0102*** (3.4389)	0.0110*** (3.6211)				
Public			0.0401*** (-4.6927)	-0.0326*** (-3.9155)					-0.0320*** (-2.6695)	-0.0245** (-1.9972)		
Cooperation					0.0039*** (5.9087)	0.0044*** (6.0918)					0.0046***(16.5157)	0.0050***(17.8462)
VER	0.0607*** (2.8709)	0.0518** (2.3970)	0.0597*** (2.8209)	0.0510** (2.3601)	0.0584*** (2.8013)	0.0490** (2.3116)	0.0781*** (3.6659)	0.0729*** (3.3399)	0.0781*** (3.6626)	0.0732*** (3.3537)	0.0739***(3.5276)	0.0681***(3.1880)
VER×POST	0.0753***(2.7662)	0.0746***(2.7216)	0.0734***(2.6932)	0.0682**(2.5304)	0.0665**(2.4584)	0.0573**(2.1557)	0.0542**(1.9923)	0.0559**(2.1033)	0.0533*(1.9597)	0.0520**(1.9918)		0.0483*(1.8146)
Contro	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No
Industry	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No
Area	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No
Pseudo R2	0.1982	0.1993	0.1994	0.1998	0.2191	0.2242	0.1290	0.1271	0.1279	0.1252	0.1613	0.1641
Obs.	7323	7323	7323	7323	7323	7323	7323	7323	7323	7323	7323	7323

we verify a significant positive correlation between government subsidies and green technology innovation (Columns 1-2 and seven to eight in **Table 5**). Whether or not the time, industry, and region are controlled and whether or not the amount of green patent grants that are postponed for one period is used, government subsidies promote green technology innovation of enterprises to a certain extent. Therefore, according to the identification logic of the mediating effect model, as long as it is confirmed that voluntary environmental regulation has a significant positive effect on government subsidies, it can be confirmed that voluntary environmental regulation will affect the green technological innovation of enterprises through the effect of government subsidies. Columns 1) and 4) in **Table 6** reported the net impact of voluntary environmental regulation on government subsidies under control and non-control of time, industry, and regional factors, which were 0.13, respectively, but not significant. It can be seen that the implementation of voluntary environmental regulation does not help enterprises obtain government subsidies, which is inconsistent with the assumption of H2 that enterprises implementing voluntary environmental regulation do not promote their green technology innovation process by obtaining government subsidies.

4.4.2 Public Support Effect

Theoretical research shows that the negative impact of voluntary environmental regulation on public support will further affect its green technology innovation effect (Demirel and Danisman, 2019; Globocnik and Faullant, 2021). On the one hand, the improvement of public awareness of environmental protection enhances the public's demand for environmentally friendly products, and on the other hand, it improves the practical legitimacy of enterprise products, which may lead to enterprises under the pressure of the downstream supply chain, sending environmentally friendly signals to consumers through voluntary environmental regulation compliance while reducing investment in green technology innovation, but it is not actually green technology innovation. In order to verify the negative effect of voluntary environmental regulation on public support, we use the mediating effect model to empirically test the public support effect of voluntary environmental regulation on green technology innovation.

In the benchmark regression equation, we verify that there is a significant negative correlation between public support and green technology innovation (**Table 5**, Columns 3-4 and 9–10). Whether or not controlling for time and area, and whether or not using the green patent authorization of the delayed phase, the strengthening of public purchasing power has inhibited the green technology innovation of enterprises to varying degrees. Therefore, according to the identification logic of the mediating effect model, as long as it is confirmed that voluntary environmental regulation has a significant negative effect on public support, it can be confirmed that voluntary environmental regulation will promote green technological innovation of enterprises through public support effect. Columns 2) and 5) in **Table 6** reported the net effect of voluntary environmental regulation on public support. It can

TABLE 6 | Test of action mechanism (2).

	Goverment	Public	Cooperation	Goverment	Public	Cooperation
	(1)	(2)	(3)	(4)	(5)	(6)
VER×POST	0.1289 (0.1984)	-0.0883*** (0.0238)	2.3074* (1.3559)	0.1337 (0.2020)	-0.0850*** (0.0229	2.2270** (0.9758)
Control	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	No	No	No
Industry	Yes	Yes	Yes	No	No	No
Area	Yes	Yes	Yes	No	No	No
Pseudo R^2	0.1189	0.0401	0.2249	0.0433	0.0331	0.1826
Obs	7,323	7,323	7,323	7,323	7,323	7,323

be seen that, whether or not the time, industry, and regional factors are controlled, the implementation of voluntary environmental regulation reduces the public support of enterprises, and the marginal coefficients are -0.09, which is consistent with H3. It is further speculated that greenwash has become a common phenomenon. With the enhancement of public awareness of environmental protection, the public realizes that enterprises implement voluntary environmental regulation in order to obtain identity and regard the implementation of voluntary environmental regulation as a green behavior of enterprises. This is intended to reduce the purchase of products labeled as green, increase the demand for "real green" products, and promote enterprises to carry out green technology innovation.

4.4.3 Enterprise Cooperation Effect

Theoretical research shows that the positive impact of voluntary environmental regulation on enterprise cooperation will further affect its green technology innovation effect. Through open innovation and cooperation with external partners, enterprises can share risks with partners and improve their motivation for green technology innovation (West and Gallagher, 2010). In addition, complementary resources that they do not have can be used to enhance the ability to solve problems, improve learning efficiency, and promote green technology innovation (Sakibara and Branstetter, 2003; Duysters and Lokshin, 2011; Di Minin et al., 2016).

In order to verify the positive impact of voluntary environmental regulation on corporate cooperation support, we use the mediating effect model to empirically test the corporate cooperation effect of voluntary environmental regulation on green technology innovation. In the benchmark regression equation, we verify a significant positive correlation between external cooperation of enterprises and green technological innovation (Columns 5-6 and 11-12 in **Table 5**). Whether or not controlling for time and area, and whether or not using the green patent authorization of the delayed phase, the strengthened external cooperation has, to some extent, contributed to the green technology innovation of enterprises. Therefore, according to the identification logic of the mediating effect model, as long as it is confirmed that voluntary environmental regulation has a significant positive effect on enterprise cooperation, it can be confirmed that voluntary environmental regulation will affect enterprise green technology innovation through the enterprise cooperation effect. Columns 3) and 6) in **Table 6** reported the net effect of voluntary environmental regulation on enterprise cooperation. It can be seen that whether or not the time, industry, and regional factors are controlled, the implementation of voluntary environmental regulation promotes the cooperation between enterprises and external enterprises, and the marginal coefficients are 2.31 and 2.23, respectively, which is consistent with Hypothesis H4. That is, the implementation of voluntary environmental regulation helps enterprises expand cooperation with external enterprises and promote their green technological innovation.

5 CONCLUSION AND IMPLICATIONS

This study uses the PSM-DID model to analyze the net effect and heterogeneity of voluntary environmental regulation on green technological innovation of enterprises and further discusses the influencing mechanism of voluntary environmental regulation on green technological innovation. The main conclusions are as follows. Firstly, regardless of whether the time, industry, and regional factors are controlled, voluntary environmental regulation has a significant positive effect on enterprises' green technology innovation, and its marginal effect is 15.05–18.98%. Secondly, compared with enterprises in other industries with pollution emission levels, voluntary environmental regulation only has a significant positive effect on green technology innovation of enterprises in mild pollution industries. Thirdly, compared with small- and medium-sized enterprises, the implementation of voluntary environmental regulation by large-scale enterprises can better promote their green technological innovation. Fourthly, compared with state-owned enterprises, voluntary environmental regulation plays a more prominent role in promoting green technological innovation of private enterprises. Fifthly, the implementation of voluntary environmental regulation will not help enterprises to promote their green technological innovation process by obtaining government subsidies but will have a positive impact on their green technological innovation by inhibiting enterprises to obtain public support and expanding cooperation with external enterprises.

As an environmental regulation with flexibility and autonomy, voluntary environmental regulation can indeed promote the process of green technological innovation of enterprises. For manufacturing enterprises, it might be feasible to explore the future path of green innovation development, realize green development and efficiency growth, and implement voluntary environmental regulation. As far as the government is concerned, innovation subsidies can indeed promote the output of green technology innovation of enterprises. In order to reduce the mismatch of resources and truly promote the process of green technology innovation, the government should introduce subsidy policies for the heterogeneous effects of green technology innovation of enterprises, subsidize enterprises with subsidy needs to implement voluntary environmental regulation, and improve the incentive effect of subsidies. For the public, firms can improve environmental awareness, learn environmental knowledge, enhance the ability to identify environmental products, and reduce the purchase of products labeled as green so as to reverse-promote green technology innovation from the consumer side. For external enterprises, the cooperation and sharing experience among enterprises can promote the green technological innovation effect of voluntary environmental regulation. Therefore, we can jointly establish technological innovation cooperation alliance, build the inter-enterprise cooperation platform, expand inter-enterprise cooperation, enhance the stability of enterprise cooperation, and provide a stable external environment for the green technological innovation of enterprises. In short, the promotion of green technology innovation effect of voluntary environmental regulation cannot be attributed to government policy forces, but should rely on the common efforts of the public, enterprises and other market players. For the public, we should rationally reduce the purchase of products labeled as green so as to curb the motivation of enterprises to implement voluntary environmental regulation, and guide enterprises to carry out green technology innovation independently from the consumer side. For enterprises, the green technology innovation effect of voluntary environmental regulation should be strengthened by establishing cooperative alliance.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material,** further inquiries can be directed to the corresponding authors.

AUTHOR CONTRIBUTIONS

G-QN: Conceptualization, Writing—original draft preparation. Y-FZ: Methodology, Formal analysis. W-PW: Supervision, Writing—review and editing. W-HX: Investigation, Data curation. K-XW: Software, Visualization. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenrg.2022.889037/full#supplementary-material

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