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Research on the cultivation of green competitiveness among chinese heavily polluting enterprises under country/district environmental regulations

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The development of the world economy has caused serious environmental pollution, which has resulted in an ecological crisis. With the acceleration of economic development, China's ecological crisis is becoming more serious. Green technology innovation is an important driving force in realizing green economic development, and heavily polluting enterprises are the key link to cultivating green technology innovation. The Porter hypothesis holds that environmental regulation has a promoting effect on enterprises' green technology innovation, but this is not reflected in the context of China. As a basic administrative unit, the implementation of environmental regulations in counties and districts determines the effectiveness of environmental policies. Utilizing structural equation modeling, this study analyzes the cultivation of the green technology innovation ability of heavily polluting enterprises under environmental regulations. The results show that command-based environmental regulation can effectively promote enterprises' green technology innovation ability. Incentive-based environmental regulation needs to be strengthened to drive the development of enterprises' "three wastes" treatment innovation ability. Voluntary environmental regulation does not effectively promote green process innovation and "three wastes" treatment innovation. In addition, enterprises' current "three wastes" treatment innovation capacity is not enough to promote the improvement of enterprises' green competitiveness. The results of this article show that environmental regulation is conducive to the green innovation ability of enterprises, and this promotion effect needs to be further strengthened. Moreover, the highlighted research limitations will contribute to the subsequent research work.

KEYWORDS

county, "porter hypothesis", environmental regulation, heavily polluting enterprises, green technology innovation

1 Introduction

The Porter hypothesis believes that environmental regulation is conducive to the development of technological innovation. The current research lacks to study the impact of the implementation of environmental regulation from the perspective of county and district. At the same time, in order to cultivate the green competitiveness of enterprises, technological innovation is essential. The mechanisms between environmental regulation, technological innovation and green competitiveness have yet to been revealed. Since the first industrial revolution, the development of the world economy has been on the fast track. However, the price of development is serious damage to the environment, and the sustainability of the ecosystem is at risk. Economic globalization has brought about a serious crisis in the world's ecological diversity (Rehman et al., 2021a, 2021b, 2021c; Rehman et al, 2022a, 2022b, 2022c, 2022d). China's economic development also follows the same path, with rapid economic development at the cost of the ecological environment. If harmonious development between ecology and the economy cannot be achieved, Chinese economic growth will not endure, leading even to ecosystem recession. The environment has constrained the development of cities (Wang et al., 2022a; Wang et al., 2022b). Innovation can be used as a supplement to environmental policy to achieve sustainable economic development (Weimin et al., 2022). The 2019 Global Environmental Performance Index Report pointed out that Chinese air quality is ranked the fourth lowest in the world, and the contradiction between economic growth and environmental constraints is intensifying. The report of the 19th National Congress of the Communist Party of China called for the need to use the market to build a new green technology innovation ecology to drive the growth of China's ecological economy. The green industrial development plan (2016–2020) particularly emphasized that the green technology innovation capacity has become a key link in maintaining the healthy economic development of China's various regions.

It is necessary for ecological governance to focus on heavily polluting enterprises, which pose a serious threat to ecological and environmental protection (Yao Y et al., 2022). If the ecological harm of heavily polluting enterprises is effectively controlled, the unfavorable situation of Chinese ecological and economic development will be fundamentally reversed. Green technology innovation is the key channel for heavily polluting enterprises to mitigate the ecological risk, protect the ecological environment, and deepen green growth (Liang and Luo, 2019). Green technology innovation is thus attracting the attention of the whole of society.

In 1994, as the founders of the green technology concept, Braun and Wield (1994) asserted that green technology is the total combination of technologies, processes, and products. These authors asserted that green technology can maintain the ecological environment, reduce resource consumption, and improve production efficiency (Braun and Wield, 1994). Green technology innovation represents science and technology, as well as ecology and the economy, integrating the characteristics of "green," "technology," and "innovation." The European Commission believes that green technological innovation is a comprehensive term that represents technology, processes, and products, which follows internal laws pertaining to ecological economic development. Further, green technological innovation could reduce resource consumption, improve energy efficiency, reducethreats to the ecological environment, and minimize the negative ecological effects. Among them, the "three wastes" treatment innovation ability is the focus. The "three wastes" refer to the waste water, waste gas and solid wastes produced in the production process of enterprises, which cause the greatest harm to the environment. Therefore, it is necessary to make breakthroughs and realize the harmless treatment of the three wastes as soon as possible.

In the early 1990s, Professor Michael Porter, an economist at Harvard University, analyzed the potential links between technological innovation and environmental regulation. He asserted that moderate environmental regulation can encourage enterprises to adopt advanced technology, reduce environmental costs, and implement profit maximization innovation behavior, subsequently improving enterprises' market competitiveness (Liu et al., 2018). Technological progress is conducive to the improvement of green products, and environmental regulation is an important driving force of technological progress (Liu et al., 2020). In China, there are three views concerning the Porter hypothesis: the first believes that the technological innovation of Chinese enterprises benefits from environmental regulation; the second is that the obstacles to enterprises' technological innovation come from environmental regulation; and the third is that it remains uncertain whether enterprise technological innovation is related to environmental regulation (Xu, 2020).

Environmental regulation is an indispensable link in establishing a green technology innovation strategy in line with the demand for market guidance (Qalati et al., 2022). Environmental regulation also reflects the internal demand and internal laws of the market economy. Lin et al. (2019) analyzed Chinese cities' panel data and found that environmental regulation has both local and neighborhood effects in promoting green technology innovation ability, and that the latter is more significant. The diffusion effect of green policies should be brought into play to assist surrounding cities in developing a green economy (Yu et al., 2021). Miao et al. (2019), based on an unbalanced panel data study of manufacturing companies in China's A-share listed companies, found that enterprises' green technology innovation ability changed synchronously with the strength of local governments'environmental regulations. At the same time, government environmental regulations help enterprises to

obtain external financing and improve their ability to innovate green technologies (Yu and Chen, 2015). Using listed enterprises in China's heavy pollution industry as a sample, Nanbo (2019) found that the green attention of the senior executive team plays an intermediary effect in environmental regulation and enterprises' green technology innovation. Xiao et al. (2020) found that the improvement of green total factor productivity in resource-based industries has benefited from the green independent innovation brought about by environmental regulation. China's current economic development model has not brought tangible improvement to total factor productivity, indicating that reform is imperative (Li and Lin, 2017). The rapid development of industrialization and manufacturing at the cost of the environment has damaged the ability to ensure sustainable economic development (Rehman et al., 2022b).

As a large number of countries have put forward increasingly stringent environmental regulation policies, and many green innovative technologies have emerged (Herman and Xiang, 2022). Under the ecological crisis, the development of corporate social responsibility also promotes technological innovation, thus leading to green development (Javeed et al., 2021). Governments need to set policies to ensure a balance between economic growth and environmental sustainability (Rehman et al., 2022c). Environmental regulation promotes the improvement of enterprises' green technology innovation ability and is conducive to the alleviation of ecological crises. However, the driving effect is not clear for heavily polluting enterprises. Counties and districts are the basic administrative units and are in a pivotal position in the Chinese administrative system. The environmental regulations of counties and districts do not only carry out the tasks and objectives of superior environmental regulations, but also directly stimulate or constrain the ecological behaviors of enterprises. Therefore, under the Porter hypothesis, an in-depth study of the cultivation of green competitiveness through county/district environmental regulation in heavy polluting enterprises is helpful to enhance enterprises' competitiveness and deepen the application of environmental regulation theory.

Focusing on grass-roots administrative units, this paper explores the impact of current environmental regulations on heavily polluting enterprises. Specifically, this paper examines the green governance of heavily polluting enterprises in order to improve the ecological environment. It also aims to verify the effectiveness of the Porter hypothesis in the context of China, thus providing a theoretical basis for environmental regulation. Based on evaluating relevant documents, environmental regulation policies for Chinese enterprises are proposed, thus filling gaps in environmental regulation research in the context of counties and districts. This provides a more feasible path for the region in addressing environmental pollution. The promotion effect of different types of environmental regulations on heavily polluting enterprises' green technology innovation ability is also verified. Finally, this paper aims to reveal the shortcomings of current environmental regulations in order for targeted improvements to be implemented.

2 Literature review and hypothesis development

According to the traditional environmental economic theory, environmental protection behavior is the burden of enterprise development and leads to synergy between social welfare and private costs. Enterprise investment in research resources helps to improve innovation capacity, but it needs government support (Ye et al., 2021). Political instability can create a crisis of ecological destruction (Adebayo, 2022a). At the same time, enterprises need to use the power of the government to achieve more comprehensive environmental governance to ensure that the behavior of individual enterprises does not damage the overall ecological environment (Yin et al., 2021). Based on the Porter hypothesis, appropriate environmental regulation has the ability to stimulate enterprises' innovation potential and improve innovation efficiency. That could make up for the increase in production costs under environmental regulation, produce an innovative compensation effect on production costs, and subsequently generate net income.

2.1 Analysis of command-based environmental regulation on heavily polluting enterprises' green technology innovation

Command-based environmental regulation can compulsorily cultivate heavily polluting enterprises' green technology innovation capability (Nie et al., 2022). Improper disposal of the "three wastes" by enterprises will seriously damage the local environment (Rehman et al., 2022d). Innovation activities of enterprises are conducive to the mitigation of environmental degradation (Fareed et al., 2022). Local governments ensure the prevention and control of environmental pollution by making environmental protection decisions (Pan and Chen, 2021). The governments at all levels in China have formulated strict environmental protection systems to ensure enterprises' ecological protection. This has entailed strict regulations on product performance, production processes, and enterprises' "three wastes" emissions. These regulations are stringently enforced by the organs of power. There is no doubt that such mandatory measures can force enterprises to take measures to achieve green technology innovation; otherwise, they will be punished by government departments (Chen et al., 2018). Heavily polluting enterprises are the key objects of government supervision. Illegal emissions from enterprises will seriously damage the local environment (Peng et al., 2021).

Command-based environmental regulation effectively stimulates enterprises' green technology innovation. Compulsory environmental regulation has promoted the development of green innovation in enterprises (Zhong and Peng, 2022). The implementation of environmental regulations at or above the provincial level varies between counties and districts. At the same time, counties will also formulate environmental regulations adapted to their ecological environment. Therefore, different regions have different effects through environmental regulation on promoting green technology innovation. Political relations affect the performance of green innovation of enterprises (Cailou et al., 2021). Command-based environmental regulation is the foundation of the entirety of environmental regulation. It is also the basis for ensuring the progressive advancement of environmental regulation. Accordingly, we posit three hypotheses:

H1a: Command-based environmental regulation has the ability to promote heavily polluting enterprises' green product innovation ability.

H1b: Command-based environmental regulation has the ability to promote heavily polluting enterprises' green process innovation ability.

H1c: Command-based environmental regulation has the ability to promote heavily polluting enterprises' "three wastes" treatment innovation ability.

2.2 Analysis of incentive-based environmental regulation on heavily polluting enterprises' green technology innovation

Incentive-based environmental regulation has the ability to continuously maintain heavily polluting enterprises' green technology innovation (Wang et al., 2021). Government incentives can solve the pain points of enterprise demand (Rehman et al., 2022b). Incentive-based environmental regulations, including environmental taxes, green subsidies, the system of tradable permits, etc., have been implemented successively in various regions of China. This has stimulated the vitality of heavy polluting enterprises' green technology innovation and supplemented command-based environmental regulation. Through establishing perfect incentive treaty, the effectiveness of environmental regulation policy can be guaranteed (Tang et al., 2021). Incentive-based environmental regulation can further promote heavily polluting enterprises' green technology innovation power in ways that command-based environmental regulation cannot. By actively taking environmental protection measures, enterprises can attract young talents and improve their innovation ability (Yao L et al., 2022). Under incentive-based environmental regulation, enterprises will take the initiative to upgrade the environmental protection requirements of products, refine green processes, and improve the efficiency of "three wastes" treatment. They can thus obtain more benefits, such as environmental tax preferences, green financial subsidies, and the right to implement emission permits (Yang et al., 2020). The implementation of incentive-based environmental regulation can realize environmental protection through technological progress (Li et al., 2019). The improvement of the environment will bring about simultaneous economic growth (Adebayo et al., 2022a, 2022b). The promotion effect of incentive-based environmental regulations is persistent. There are regional differences in the implementation quality and effect, so the impact on the green technology innovation of heavy polluting enterprises is also different. Although there are common policies, the differences in local customs require environmental regulations to be implemented precisely in accordance with local conditions (Zhang et al., 2021). At present, there is no doubt that incentive-based environmental regulation has an incentive effect, but the internal incentive structure of heavy polluting enterprises' green technology innovation has not yet been revealed. In order to further clarify the above discussions, the following hypotheses are formulated:

H2a: Incentive-based environmental regulation has the ability to promote heavily polluting enterprises' green product innovation ability

H2b: Incentive-based environmental regulation has the ability to promote heavily polluting enterprises' green process innovation ability.

H2c: Incentive-based environmental regulation has the ability to promote heavily polluting enterprises' "three wastes" treatment innovation ability.

2.3 Analysis of voluntary environmental regulation on heavily polluting enterprises' green technology innovation

Voluntary environmental regulation has the ability to improve heavy polluting enterprises' green technology innovation flexibly. Environmental pollution is an important reason hindering the sustainable development of society (Adebayo et al., 2022). China's industrial system determines the massive consumption of fossil energy (Akadiri et al., 2022). Heavy polluting enterprises produce a large number of greenhouse gases in the production process, which damages the local and global environment. Therefore, technological innovation is needed to alleviate environmental pollution (Rehman et al., 2021a, 2021b, 2021c). The improvement of the environment will inevitably bring about the ecological optimization (Yao Y et al., 2022). Many uncertainty factors can affect enterprises' green technology innovation, including environmental and technical uncertainty. Therefore, it cannot advance following the established process in a step-by-step manner; it will be interfered with by various external forces and requires flexible incentive methods. The flexible government

environment system will encourage enterprises to adjust financial structure and achieve green transformation (Yang et al., 2022). In this context, voluntary environmental regulation has come into being. The development of green economy cannot be separated from the voluntary behavior of enterprises (Kolcava and Bernauer, 2021). Voluntary environmental regulation supplements command-based environmental regulation and also lays a solid foundation for the implementation of incentive-based environmental regulation (Wei and Zhang, 2020). The green technology innovation ability of many heavily polluting enterprises in China is in a critical period. Adapting to the command-based and incentive-based environmental regulations is difficult, while voluntary environmental regulation is easier to adopt. The effectiveness of voluntary environmental regulation is affected by the local industrial structure (Zhou et al., 2022). The implementation conditions, methods, and effects of voluntary environmental regulation vary greatly between the different regions in China, with different degrees of effect on heavy polluting enterprises' green technology innovation. Based on the above discussion, three hypotheses are formulated:

H3a: Voluntary environmental regulation has the ability to promote heavily polluting enterprises' green product innovation ability.

H3b: Voluntary environmental regulation has the ability to promote heavily polluting enterprises' green process innovation ability.

H3c: Voluntary environmental regulation has the ability to promote heavily polluting enterprises' "three wastes" treatment innovation ability.

2.4 Analysis of heavily polluting enterprises' green innovation ability on green competitiveness

The seminal management scholar Peter Drucker once said that core competitiveness is the key to any enterprise. In the wake of ecological economics, green competitiveness has become the key to enterprise development. Only in accordance with the law of green economic development, enterprises can obtain the potential for sustainable development. Economic development needs to be integrated with environmental planning to achieve sustainable development (Rehman et al., 2021c). Effective environmental protection mechanism can promote technological innovation and industrial structure upgrading (Fan et al., 2022; Zhuo et al., 2022). In the green economy, the source of enterprises' green competitiveness is green innovation ability. Any growth in green innovation ability will drive the development of enterprises' green competitiveness (Yan et al., 2020). The development of green technology will effectively avoid the decline of market competitiveness brought about by the carbon emission trading system (Wang and Zhang, 2022). A heavily polluting enterprise's lifeline is green technology innovation, which aims to cultivate green competitiveness (Chen et al., 2022). Meanwhile, the development of green competitiveness inversely urges the realization of green technology innovation (Zameer et al., 2021). The forms and standards of green technology innovation are different in different industries or enterprises, but the ultimate goal is the same. With the deepening of technological innovation, green technology innovation has received increasing attention in China's heavily polluting enterprises. It has become an essential means for heavily polluting enterprises to compete in international and domestic markets. Accordingly, we posit the following hypotheses:

H4a: Heavily polluting enterprises' green product innovation ability can promote their green competitiveness.

H4b: Heavily polluting enterprises' green process innovation ability can promote their green competitiveness.

H4c: Heavily polluting enterprises' "three wastes" treatment innovation ability can promote their green competitiveness.

2.5 Establishment of the research model

In this study, structural equation modeling (SEM) was chosen to comprehensively verify the research hypotheses (Ostic et al., 2021). Data indexes that lack validity and reliability can be deleted from the structural equation model to ensure data reliability. With this method, the path relationship between indicators can be displayed, and invalid paths can be quickly found according to the test results, enabling the targeted improvement of invalid paths. This study involves many variables, so the structural equation model can be used to comprehensively consider the complex relationship between these variables. According to the ideas and methods of SEM, the research model was constructed by synthesizing the research hypotheses, as shown in Figure 1, which contains three exogenous variables, four endogenous variables, and 12 causal paths.

Through the structural equation model, the impact of different types of environmental regulations on the green technology innovation ability of enterprises can be clearly described, and then the improvement of green competitiveness can be achieved. With this, the government can improve its own environmental regulation policies in time according to the inspection results. At the same time, enterprises can use environmental regulation to find a way to promote their own technological innovation capabilities, so as to obtain better market competitiveness. To achieve sustainable development goals through ecological improvement is the common pursuit of the government and enterprises.

3 Research methodology

3.1 Decomposition of elements

The elements decomposition includes three parts: the elements decomposition of county and district environmental

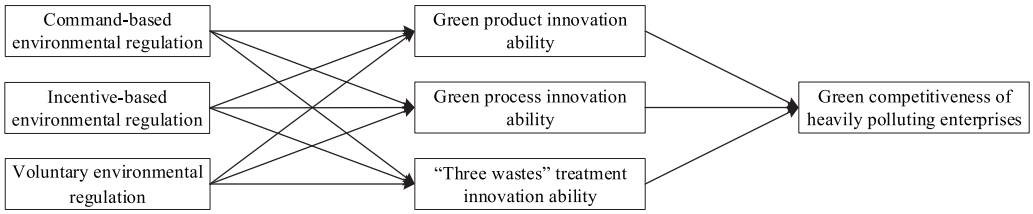

FIGURE 1
Research model.

regulation; the elements decomposition of heavily polluting enterprise technological innovation; and the elements decomposition of enterprises' green competitiveness.

3.1.1 Elements decomposition of county and district environmental regulation

Based on existing research, the elements of command-based environmental regulation are divided into the following four indexes in this study: 1) the government has formulated clear environmental protection standards for the product performance of heavily polluting enterprises and has strictly implemented them; 2) the government has formulated clear environmental protection standards for the production processes of heavily polluting enterprises and has strictly implemented them; 3) the government has formulated clear environmental protection standards for the "three wastes" emissions of heavily polluting enterprises and has strictly implemented them; and 4) the government's green environmental protection standards are constantly adjusted flexibly in line with changes in the internal and external environment of heavily polluting enterprises (Walter and Chang, 2020).

Based on existing research, the elements of incentive-based environmental regulation are divided into the following four indexes in this study: 1) the government's environmental protection tax collection for heavily polluting enterprises is highly scientific, reasonable, and fair; 2) the government's green financial subsidies for heavily polluting enterprises are highly open, targeted, and fair; 3) the government has a pollutant discharge permit system for heavily polluting enterprises with high fairness, transparency, and supervision; and 4) the government flexibly implements incentive-based environmental regulations for heavy polluting enterprises to deal with changes in the external environment (Xu and Liu, 2020; Ren et al., 2022).

Based on existing research, the elements of voluntary environmental regulation are divided into the following four indexes in this study: 1) the government attaches importance to education and publicity regarding voluntary environmental regulation for heavily polluting enterprises; 2) the government has cultivated effective ecological ethics for heavily polluting enterprises; 3) the government's voluntary environmental regulation design for heavily polluting enterprises has high rationality, fairness, and transparency; and 4) the government constantly improves the market regulation mechanism on which voluntary environmental regulation depends (Kang et al., 2020).

3.1.2 Elements decomposition of heavily polluting enterprises' green technology innovation

After comprehensively consulting the relevant research, we divided the green product innovation elements of heavy polluting enterprises into the following four indexes: 1) enterprises' products meet the needs of the green market, in terms of the development concept, and contribute to the development of ecological and environmental protection; 2) in the process of storage and transportation, enterprises strictly choose green ways to meet the needs of ecological and environmental protection; 3) the application or consumption of enterprises' products can lead to an increase in, and the development of, green consumption ideas and behaviors; and 4) corporate decision-makers attach importance to, and promote, green product innovation, and create incentive clauses that contribute to green development (You et al., 2019).

Based on existing research, the elements of green process innovation of heavily polluting enterprises are divided into the following four indexes in this study: 1) enterprises attach great importance to the design and improvement of green processes during product design; 2) enterprises in raw material procurement aim to increase the selection and use of green raw materials; 3) enterprises focus on the selection and improvement of the green performance of production equipment and safety equipment; and 4) enterprises aim to improve the use and transformation of green technology in product quality inspection and packaging (Zhang et al., 2020).

Based on existing research, the elements of the "three wastes" treatment of heavily polluting enterprises are divided into the following four indexes in this study: 1) enterprise wastewater treatment technology is constantly innovating; 2) enterprise waste gas treatment technology is undergoing continuous innovation; 3) enterprise waste residue treatment technology

is undergoing continuous innovation; and 4) enterprise decision-makers attach importance to innovation in waste technology from start to finish (Wang and Yang, 2020).

3.1.3 Elements decomposition of heavily polluting enterprises' green competitiveness

Based on existing research, the elements of heavily polluting enterprises' green competitiveness are divided into the following four indexes in this study: 1) the green quality or characteristics of the enterprise products have been upgraded; 2) the environmental protection reputation of enterprise products has improved; 3) the green competitive advantage of enterprise products in the industry is more obvious; and 4) the strategic decision of enterprises can follow the internal laws of the green economy or ecological economy development (Cai and Teng, 2020; Hussain et al., 2022).

3.2 Sample and population

In this study, a seven-point likert scale was used to collect data, and the sample units were heavily polluting enterprises in China. To maintain the uniformity of the sample distribution, one heavily polluting enterprise was chosen in each county and district. In order to improve the quality of the data, the following three collection methods were adopted. First, an environmental regulation questionnaire regarding the county/district government environmental regulations was filled out by the enterprises. This is because enterprises can accurately judge the effectiveness and efficiency of government environmental regulation. Second, heavily polluting enterprises' green innovation ability questionnaires were filled out by the county and district environmental protection departments. This is because the environmental protection departments can objectively judge the green technology innovation level of enterprises. Third, a questionnaire on the green competitiveness of heavily polluting enterprises was filled in by enterprises and environmental protection departments together and then averaged. This enabled a more scientific and comprehensive understanding of enterprises and environmental protection departments.

According to the list of enterprises that need to focus on environmental issues published by the State Environmental Protection Administration, there were 1,000 enterprises selected for investigation. To ensure the reliability of data, we chose heavily polluting enterprises, a high proportion of which included the chemical industry and the smelting and casting industry. The enterprises were located in seven regions of China to reflect the differences in environmental regulations. The scale of enterprises covered a wide range, because the pollution caused by small enterprises is no less than that of large enterprises, and the number of small enterprises is far greater than that of large and medium-sized enterprises. After determining the enterprise sample, the questionnaire was distributed, and 889 samples were received. Finally, 400 samples with high data quality were selected for the reliability test, validity test, and full model test. Table 1 summarizes the characteristics of the samples. Table 2 presents the data characteristics of the samples, in which the element values were obtained by averaging the values of the indexes to which the elements belong.

4 Model testing and result analysis

4.1 Model testing

Regarding the reliability and validity tests for each element, sample data (n = 400) were verified using SPSS18.0 software. The KMO value was 0.836, Bartlett's test of sphericity value was 0.00, and the Cronbach' α value was 0.851, indicating that the questionnaire data passes the reliability test. The index factor loading values and the goodness-of-fit indices were within the suggested range. Based on the reliability test and validity test results, SPSS18.0 and Lisrel8.0 were used to test the whole model. Table 3 presents the results of the full-model tests.

Test results indicated that *H2c*, *H3b*, *H3c*, and *H4c*were not supported, while the remaining hypotheses were supported. The goodness-of-fit indicesare shown in Table 4. According to the comprehensive judgment of the degree of index compliance, the model fitting effect is considered to be good, and there is no need to modify the model.

4.2 Model test results

The test results revealed that the environmental regulation of county and district governments in China promotes heavily polluting enterprises' green technology innovation ability and green competitiveness. However, environmental regulation has not realized its full potential to promote green technology innovation and may hinder the growth of enterprises' green competitiveness. Therefore, county and district environmental regulation needs to be improved.

Specifically, command-based environmental regulation is shown to be a better incentive for green technology innovation ability than incentive-based environmental regulation, while incentive-based environmental regulation is better than voluntary environmental regulation. Environmental regulation is more effective in promoting green product innovation ability than green process innovation ability, while the promotion effect of "three wastes" treatment innovation ability is the least effective. Moreover, green product innovation ability and green process innovation ability are shown to effectively promote heavily polluting enterprises' green competitiveness, but the "three

TABLE 1 Sample characteristics.

Properties	Type	Sample size	Share %	Properties	Type	Sample size	Share %
Industry distribution	Printing and dyeing	20	5	Staff size distribution	1–200	64	18
	Paper making	16	4		201–400	88	22
	Tanning	16	4		401–600	96	24
	Chemical	60	15		601–800	56	14
	Rubber	24	6		801–1,000	48	12
	Smelting and casting	40	10		>1,000	40	10
	MSG manufacturing	16	4	Established time distribution (years)	1–2	64	16
	Natural gas extraction	12	3		3–4	68	17
	Additive manufacturing	20	5		5–6	88	22
	Manufacture of starch products	24	6		7–8	72	18
	Woolen processing	24	6		9–10	60	15
	Silk reeling processing	20	5		>10	48	12
	Plywood manufacturing	16	4	Profits distribution	<1 M	76	19
	Fiberboard manufacturing	16	4		1–2 M	92	23
	Furniture manufacturing	16	4		2–3 M	80	20
	Feed processing	20	5		3–4 M	64	16
	Other industries	40	10		4–5 M	56	14
Geographical area distribution	Eastern China	64	16	Fixed assets distribution	>5 M	32	8
	South Central Region	56	14		<10 M	88	22
	Northern China	76	19		10–20 M	96	24
	Northwest Territories	52	13		20–30 M	76	19
	South West	52	13		30–40 M	60	15
	Northeast China	40	10		40–50 M	44	11
	South East	60	15		>50 M	36	9

TABLE 2 Sample data characteristics.

Element	Maximum value	Minimum value	Average value	Variance
Command-based environmental regulation	7	2	3.78	0.23
Incentive-based environmental regulation	7	1	3.31	0.17
Voluntary environmental regulation	7	1	2.89	0.31
Green product innovation ability	7	2	3.12	0.25
Green process innovation ability	7	2	2.91	0.09
"Three wastes" treatment innovation ability	7	2	3.26	0.18
Enterprises' green competitiveness	7	1	2.87	0.20

wastes" treatment innovation ability lacks the ability to promote enterprises' green competitiveness.

In short, while deepening the incentive-based environmental regulation and voluntary environmental regulation in counties and districts, there is a need to enhance the green process innovation ability and the "three wastes" treatment innovation ability. This will allow heavily polluting enterprises' green competitiveness to reach a higher level.

5 Discussion

This paper has studied the relationship between environmental regulation and enterprises' green technology innovation using structural equation modeling. We divided environmental regulation into three types (command-based, incentive-based, and voluntary) in order to verify the improvement effect of enterprises' innovation ability under

TABLE 3 Model test results.

Hypothesis	Content	Path coefficient	*t*-value	Test results
H1a	Command-based environmental regulation perception → green product innovation capability	0.33	4.81	Supported
H1b	Command-based environmental regulation perception → green process innovation capability	0.31	5.29	Supported
H1c	Command-based environmental regulation perception → "three wastes" treatment innovation ability	0.27	2.79	Supported
H2a	Incentive-based environmental regulation perception → green product innovation capability	0.30	3.64	Supported
H2b	Incentive-based environmental regulation perception → green process innovation capability	0.26	2.90	Supported
H2c	Incentive-based environmental regulation perception→ "three wastes" treatment innovation ability	0.11	1.87	Not supported
H3a	Voluntary environmental regulation perception→ green product innovation capability	0.29	6.10	Supported
H3b	Voluntary environmental regulation perception → green process innovation capability	0.08	1.02	Not supported
H3c	Voluntary environmental regulation perception→ "three wastes" treatment innovation ability	0.10	1.71	Not supported
H4a	Green product innovation capability → green competitiveness of heavy polluters	0.29	3.86	Supported
H4b	Green process innovation capability → green competitiveness of heavy polluters	0.26	5.00	Supported
H4c	"Three wastes" treatment innovation ability → green competitiveness of heavy polluters	0.11	1.51	Not supported

TABLE 4 Goodness-of-fit indices.

Goodness-of-fit index name	Goodness-of-fit index value	Conformity
χ^2/df	1.229	High
GFI	0.930	Moderate
AGFI	0.867	Close to match
RMSEA	0.054	Moderate
NFI	0.909	Low
TLI	0.990	Highly
CFI	0.936	Moderate
AIC	98.129	Low
CAIC	178.280	High
ECVI	0.311	Moderate

different paths. The path from incentive-based environmental regulation to the "three wastes" treatment innovation ability was not verified, indicating that incentive-based environmental regulation does not promote the "three wastes" treatment innovation ability. Incentive-based environmental regulation can induce enterprises to invest resources to promote production technology innovation. However, there is a lack of measures to improve enterprises' "three wastes" treatment processes (Li et al., 2022). When subsidies are lower than investments, it is difficult for companies to invest more resources as this might damage their performance.

Voluntary environmental regulation was not shown to promote the green process innovation ability. In the development plan of an enterprise, promoting its environmental protection concept can help it build a better reputation, thus enhancing the product image. Through product innovation, the green image of the enterprise can be vividly displayed, but the production process is rarely perceived by the outside world. The existence of information asymmetry motivates enterprises to reduce their investment in production processes (Wang and Zhang, 2022). Therefore, enterprises' voluntary environmental regulation cannot ensure the realization of green process innovation. In addition, voluntary environmental regulation was not shown to improve the "three wastes" treatment innovation ability. The "three wastes" are useless assets for enterprises, requiring the spending of resources to deal with them, which goes against the nature of enterprises to pursue maximum profits (Wu et al., 2020). Innovation in the "three wastes" treatment ability cannot bring more profits to enterprises. On the contrary, resources need to be invested in technology transformation. Enterprises will not actively realize innovation in "three wastes" treatment technology under voluntary environmental regulation.

The promotion effect of the "three wastes" treatment innovation ability on the green competitiveness of heavily polluting enterprises was not verified. The reason is that

enterprises' "three wastes" treatment ability has not been significantly improved. The current environmental regulation lacks effective guidance for enterprises' "three wastes" treatment (Gaeta et al., 2021). This environmental regulation cannot fully change enterprises' behavior and urgently needs to be changed.

Command-based environmental regulation was shown to encourage enterprises to achieve green technology innovation through coercive force. Incentive-based environmental regulation provides resources to carry out technological innovation by means of government subsidies to achieve green development. The absence of voluntary environmental regulation impacts enterprises, leading to the promotion effect on the development of green technology innovation not being ideal. In addition, environmental regulation was shown to have a significant promotion effect on the green innovation ability of enterprises, indicating that the current strategies implemented in grass-roots administrative units in China are more effective. According to the results of this paper, the validity of the Porter hypothesis is fully verified in China, and environmental regulation is conducive to the improvement of enterprises' innovation ability.

6 Conclusion and policy suggestions

Based on the results of the model testing, a cultivation strategy for enterprises' green competitiveness can be proposed based on counties and districts' environmental regulations in China.

First, it is necessary to enhance the optimization of incentive-based environmental regulation in relation to the "three wastes" treatment innovation ability. At present, the improvement of the "three wastes" treatment innovation ability of heavily polluting enterprises is mainly promoted through command-based environmental regulation. Meanwhile, several means of incentive-based environmental regulation have had no obvious promotion effect. Therefore, there is a lack of improvement in enterprises' "three wastes" treatment based on environmental tax collection, preferential environmental taxes, green fiscal subsidies, or sewage permit systems. Enterprises only deal with "three wastes" emissions according to government administrative instructions, and there is a lack the motivation for technological innovation. Therefore, the tax authorities need to appropriately increase tax incentives for "three wastes" emissions and formulate incentive rules. Financial departments should improve the subsidy method for "three wastes" emissions and formulate more precise subsidy quotas. Environmental protection departments should formulate targeted discharge permit systems for heavily polluting enterprises. Further, distinguishing heavily polluting enterprises from general enterprises is necessary. Flexible measures should be taken to improve the efficiency of the discharge permit system for heavily polluting enterprises' "three wastes" treatment.

Second, it is necessary to enhance the optimization of green process innovation ability through voluntary environmental regulation. At present, voluntary environmental regulation in Chinese counties and districts has insufficient incentives for green technology innovation. The county and district environmental protection institutions should design voluntary environmental agreements for heavily polluting enterprises' green process innovation, which covers process design, material procurement, product manufacturing, equipment purchase, quality inspection, and other aspects. Comparatively speaking, in order to realize green process innovation, the design of voluntary environmental regulation is more difficult than green product innovation. Because green product innovation is shown outside the product, while green process innovation is hidden inside the product, it is difficult for environmental protection departments to accurately identify green process innovation. Therefore, to obtain deep and effective incentives for heavily polluting enterprises' green technology innovation, the county and district environmental protection departments should design and implement an in-depth analytic mechanism for green process innovation with the help of professional institutions or technical personnel. Through the development of more scientific and reasonable voluntary environmental regulations, it may be possible to achieve a breakthrough in green process innovation.

Third, there is a need to enhance the optimization of voluntary environmental regulation in relation to the "three wastes" treatment innovation ability. The design focus of voluntary environmental agreement of county and district environmental protection institutions needs to change from green product innovation to "three wastes" treatment innovation. This will increase the enthusiasm for enterprises' "three wastes" treatment technology renovation. Voluntary environmental regulation in Western countries covers various fields, including green product innovation, green process innovation, and "three wastes" treatment innovation, but in China, it is limited to green product innovation. There is therefore great opportunity for improvement in China's voluntary environmental regulation. Heavily polluting enterprises in China still have great potential in the reform of "three wastes" treatment technology. However, the weakness, or lack, of voluntary environmental regulation agreements inhibits the development of this potential. In order to improve the enthusiasm for enterprises' "three wastes" treatment technology innovation, environmental protection agencies should also cooperate with professional organizations or employ professional technicians to formulate scientific and reasonable voluntary environmental agreements. This may break the situation in which voluntary environmental regulations are seen as being stuck in the past.

Fourth, it is necessary to deepen the cultivation of the "three wastes" treatment innovation ability in the context of environmental regulation. Analysis of the characteristics of the sample data reveals that the level of China's heavy polluting enterprises' green innovation capacity is not high. There is thus potential to promote the green competitiveness of enterprises. Among them, the "three wastes" treatment innovation ability has the greatest potential. If the innovation ability of "three wastes" treatment is upgraded to a higher level, the growth of enterprises' green competitiveness will be greatly improved. Therefore, the improvement and perfection of environmental regulations in counties and districts can take the lead in focusing on the innovation ability of "three wastes" treatment, subsequently strengthening the promotion of the "three wastes" treatment innovation ability. At present, heavily polluting enterprises' green technology innovation focuses on green product innovation and green process innovation, while ignoring "three wastes" treatment innovation. This situation should be changed as soon as possible to ensure that innovation in the three green technologies is synchronized.

Fifth, there is a need to deepen the cultivation of environmental regulation in relation to enterprises' green technology innovation ability and to realize the effective linkage between counties/districts and superior units. Environmental regulation at the county/district level is responsible for promoting enterprises' pollution prevention and control. The higher administrative units command the overall situation. When the environmental regulations of counties and districts have problems, it is necessary to adjust the strategic planning together with the superior units to ensure that the goals are more in line with reality. At present, China's environmental regulation is generally effective, but there are some problems in certain links. The superior administrative units should adjust the policy direction according to these deficiencies, strengthen the command-based environmental regulation, change the voluntary environmental regulation provisions, and use incentive-based environmental regulations to stimulate enterprises' enthusiasm in order to support command-based environmental regulation.

In short, the development of China's environmental regulation has laid the foundation for the cultivation of heavy polluting enterprises' green competitiveness. The effectiveness of environmental regulation can be brought into play by combining it with local customs. It is necessary to optimize the coercive force of command-based environmental regulation to prevent the anti-ecological protection behavior of enterprises. Through the layered design of environmental taxes, the supervision of different enterprises can be achieved. It is necessary to expand the scale and scope of government subsidies to enterprises and provide compensation for enterprises' green innovation investment. There is a need to stipulate the period of subsidy for green technology innovation and to put pressure on enterprises while promoting their technological development. Certification is also required for the products produced by enterprises that actively develop green technology, and to set up corresponding green awards. With the active participation of government environmental protection agencies, tax authorities, financial institutions, and heavily polluting enterprises, it will be possible to realize the optimization of environmental regulation. This could achieve the aim of improving the green innovation ability, subsequently enhancing enterprises' green competitiveness. The acquisition of green competitiveness can help achieve the technology upgrading of China's heavy polluting enterprises. Further, it is important in completing the important task of maintaining the world's ecological environment.

Through the research of this paper, it can be found that the power of government has natural control over the areas where the market is difficult to play a role. Profit-seeking entrepreneurs want the maximum benefit at the minimum cost, and governments can change this self-seeking behavior. This has reference significance for many fields of research. Moderate government participation will achieve better social benefits. Environmental regulation can help enterprises develop green technologies and gain new market competitiveness. Developing green economy under the premise of realizing ecological stability is an urgent goal for countries in environmental crisis. The research results of this paper can provide a feasible path for it.

7 Research limitations and future prospects

This study has explored the relationship between environmental regulation and the green technology innovation ability of heavy polluting enterprises using SEM. Based on the results of the model testing, it was found that the current environmental regulation policy is inadequate, and some suggestions have been proposed in this regard. However, this paper has its limitations. First, there is a lack of in-depth analysis on environmental regulation and enterprises' green competitiveness; the formation of enterprises' green competitiveness cannot be separated from the support of government policies. Second, without an in-depth analysis of command-based environmental regulation, mandatory orders are not all good for the development of enterprises.

Future research will be conducted from the following points. First, the improvement of environmental regulation based on enterprises' technological innovation needs to be analyzed. The relationship between environmental regulation and enterprises' technological innovation is not one-way but mutually reinforcing. It is necessary to adjust the direction of environmental regulation according to the development of enterprise technology. Second, research should be carried out on the innovation ability of enterprises' "three wastes" treatment.

According to the research results, the "three wastes" treatment innovation ability has not been effectively promoted. Therefore, it would be valuable to study how best to use environmental regulation to realize the development of the "three wastes" treatment innovation ability, as well as the impact of this ability on enterprises' green development.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethics review and approval/written informed consent was not required as per local legislation and institutional requirements.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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