

Article

The Impact of Consumer Environmental Preferences on the Green Technological Innovation of Chinese Listed Companies

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Abstract: Using the data of companies from heavily polluting industries listed on China's A-share stock market from 2011 to 2022, this paper empirically investigates the impact of consumer environmental preference on green technological innovation. The results indicate that consumer environmental preference significantly promotes the green innovation of firms from heavily polluting industries. Moreover, consumer environmental preference imposes a higher influence on strategic green innovation than substantive green innovation. The mechanism tests suggest that consumer environmental preference encourages green technological innovation by strengthening the environmental protection concept and increasing R&D investment. Finally, we find that rising consumer environmental preference has a more prominent effect on the promotion of green innovation for enterprises in regions with higher levels of marketization and lower government environmental regulation, larger enterprises, and private enterprises.

Keywords: consumer environmental preferences; heavily polluting firms; green technological innovation; R&D investment



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1. Introduction

Climate change and environmental pollution are recognized as major challenges to the world's sustainable development because they lead to an increase in extreme weather events that disrupt ecosystems and decrease biodiversity [1]. The urgency of environmental protection requires rapid actions by all countries all over the world. In recent years, China has taken the construction of ecological civilization as a fundamental plan to achieve sustainable development. Guided by this plan, the Chinese government has made great efforts to transform the economic development model from extensive growth to intensive growth because economic growth heavily relies on natural resources and has inevitably led to severe environmental pollution. For example, China has set an economic goal of achieving "carbon neutrality" by 2060. In order to effectively reduce the level of carbon emissions and promote the transition to a green economy, the government agreed to launch a pilot carbon emissions trading policy in 2011 [2]. Achieving economic growth through green innovation is the only way for China to realize sustainable development and ecological civilization.

With the growth of a green low-carbon economy, rising consumer incomes, and the awakening of environmental awareness, the concept of green consumption is becoming increasingly popular. According to the annual consumer trend survey conducted by Zhimeng in 2023, 73.8% of consumers give priority to green and environmentally friendly products or brands in their daily lives. Meanwhile, another 30.6% of consumers said that green products have improved their quality of life. Consumers' concern for the ecological environment and their willingness to buy green products are gradually increasing.

The theory of Revealed Preference proposed by P. Samuelson in 1948 suggests that consumers' purchasing behavior reveals their intrinsic preference tendencies, and consumers' preferences can be shown by their actual buying behavior. Therefore, according

to the theory of Revealed Preference, the increase in green consumption indicates that the degree of consumers' environmental preference is gradually increasing [3,4]. Increased environmental preferences of consumers, who prefer green products, influence the production activities of enterprises [5]. The reason is that price competition among homogeneous products in the commodity market is very fierce, and labeling products as green is regarded by enterprises as the key to improving product competitiveness [6]. Enterprises may increase green R&D investment, improve production technology, and produce more green products in order to increase market share for more profits [6,7]. So, we can suggest that consumer environmental preferences may promote firms' green innovation.

Enterprises are practitioners in promoting green economic growth, and green innovation is the driving force for promoting the green development of enterprises [5,7]. However, green innovation is characterized by large capital investment, long R&D cycles, and high uncertainty, which often makes enterprises, especially traditional heavy polluters, prone to difficulties in green innovation [8,9]. In order to promote the green innovation of heavy polluters, the government has introduced a series of environmental regulations and financial subsidy policies [2], but to truly stimulate the willingness of enterprises to pursue green innovation, the consumer market is more important than government support [5,10].

This paper attempts to raise and address the following questions: Does an increase in the degree of consumer environmental preference promote green technology innovation in heavily polluting firms? What is the influence mechanism? Can the increase in environmental preference achieve the effect of promoting green innovation by increasing the R&D investment of enterprises? The production activities of heavily polluting enterprises provide economic benefits but also provide many ecological problems, including environmental pollution and resource depletion [1]. Exploring the green development of heavily polluting enterprises is a topic that needs to be solved urgently [2]. Therefore, this paper analyses the green innovation of heavily polluting enterprises from the perspective of consumer demand, which is conducive to cultivating green consumption as a new consumption growth point, providing a new direction for expanding domestic demand and exploring the endogenous power of economic green transformation. At the same time, this is conducive to promoting enterprise investment, forming a virtuous circle in which the demand side and the supply side mutually promote the enterprise's green technological innovation.

Existing research on consumer environmental preference mainly focuses on the influencing factors of consumer environmental preference [3,11] and the influence of consumer environmental preference on consumer product choice [12,13]. Consumers' environmental awareness and concern for environmental information are important factors influencing consumer environmental preference, and the higher consumers' concern for environmental information, the higher consumers' environmental preference will be [3,11]. Consumers with high environmental preferences are more likely to make more environmentally friendly product choices, such as choosing green products [14]. They are also more willing to pay higher prices for green products [12,15,16]. It can be seen that existing studies are more concerned with the analysis of consumer behavior [17–19], and rarely link consumer behavior to the production and innovation of micro-firms. However, enterprises are the main body of market supply, and the green demand of consumers will have an impact on the green production of enterprises [13,20]. Thus, research on the economic effects of consumers' environmental preferences and their impact on the green behaviors of micro-enterprises needs to be deepened.

To fill the gaps in previous studies, this paper uses data on corporate green patents of Chinese A-share listed companies in heavily polluting industries from 2011 to 2022; the "Baidu" environmental pollution search index; and the public environmental protection appeal index by province to study the impact of consumers' environmental preferences on the green technological innovations of heavily polluting companies. Further, based on stakeholder theory and signaling theory, this paper examines the potential influence mechanism from the perspectives of corporate R&D investment and the environmental

protection concept. We also discuss the heterogeneity of this influence under different levels of marketization and the intensity of government environmental regulation, as well as under different firm sizes and types of firm ownership. The empirical test finds that consumer environmental preferences can promote green technological innovation in heavily polluting firms, especially in large private firms with high levels of marketization and low government environmental regulations. The mechanism behind this is that consumer environmental preferences can promote green technological innovations by stimulating firms to increase R&D investment, encouraging them to establish environmental protection concepts.

This paper is expected to contribute to the existing literature on consumer environmental preference [3,11–13] with the following points: firstly, few existing studies directly link consumer environmental preferences and corporate green innovation [5,13], and this paper studies the micro-mechanism of China's consumer environmental preference on green economic growth from the perspective of consumer demand, providing theoretical support for green consumption in terms of economic transformation. The study of corporate green innovation in terms of the consumer demand of market participants provides an empirical basis for the expansion of domestic demand, market-oriented reform, and economic transformation. Secondly, this paper discusses the influence mechanism of consumer environmental preference on enterprises' green technological innovation and analyzes the role of consumer environmental preference in promoting enterprises' green innovation from two new perspectives of enterprises' R&D investment and environmental protection concepts based on stakeholder theory and signaling theory. It also explores the differentiation of consumer environmental preference on enterprise green innovation considering the market development level, government environmental-regulation intensity, and enterprise size and ownership, which expands the research perspectives of the related literature.

The rest of this paper is organized as follows: Section 2 introduces the theoretical background and develops research hypotheses. Section 3 presents the methodology framework and the data. Section 4 reports the results of benchmark regression and robustness tests. Section 5 details the mechanism test and heterogeneity analysis. Section 6 is the discussion, and Section 7 draws conclusions and explains policy implications.

2. Theoretical Background and Research Hypotheses

2.1. Consumer Environmental Preferences

Consumers' environmental preferences are the extent to which they care about the environment or their willingness to pay for environmental improvements [21]. In the 1960s, "environmental concern" was put on the policy agenda of Western countries as a social issue, and then, an increasing amount of social science research began to focus on the public's "environmental concern" [21,22]. Most studies have used questionnaires to measure environmental concerns. In 1978, R. E. Dunlap and K. D. Van Liere formally introduced the New Environmental Paradigm (NEP) scale, which has become the world's most widely used measure for investigating environmental issues and has been adopted by hundreds of studies in dozens of countries. The NEP scale measures people's concern for the environment by examining their views on the limits to economic growth, ecological balance, and the relationship between humans and nature. The NEP scale has evolved as people have become more aware of global issues such as climate change. R. E. Dunlap [22] specifically designed the New Ecological Paradigm (NEP) scale to address the shortcomings of the original NEP scale by adding a survey on people's perceptions of the relationship between humans and the environment. The New Ecological Paradigm scale has been used internationally as a measure of the public's environmental concerns and environmental values and attitudes.

In the context of a low-carbon society, consumers are becoming increasingly aware of low-carbon and environmental protection. They are not only more concerned about environmental issues but also show a growing preference for green products [17,19]. Some studies have found that consumer environmental preferences have an impact on the market

operation of enterprises from the demand side [13,16]. The reason is that consumer environmental preferences are conducive to gaining market share for firms that adopt green innovations [6,13]. When enterprises feel the green demand from consumers, in order to enhance market competitiveness and gain more market share, they increase the investment of resources in the research and development of green products [5,10]. Additionally, they further focus on the research and development of new materials, high-efficiency installations, clean production processes, recycling of resources and other green and low-carbon technologies, and promote enterprise green technology innovation [23,24]. Moreover, heavily polluting industries are more representative. The traditional production activities of heavily polluting enterprises contribute to environmental pollution and resource depletion. In order to attract consumers with green environmental preferences and obtain their market competitiveness, heavily polluting enterprises will actively adopt green technological innovation means and engage in green development [7,25,26]. Thus, we put forward the following hypothesis:

Hypothesis 1. *Rising consumer environmental preferences promote green technology innovation in heavily polluting firms.*

2.2. The Mechanism of Consumer Environmental Preferences to Promote Green Technology Innovation

2.2.1. R&D Investment

Stakeholder theory, proposed by R. E. Freeman in 1984, suggests that managers should comprehensively and fully consider the demands of relevant stakeholders before implementing business activities and that the survival and development of a company depends on the maintenance and participation of relevant stakeholders. Consumers are one of the stakeholders that influence green innovation in companies. As consumers' environmental preferences increase, according to stakeholder theory, the managers of the company adjust their development strategies to take into account consumer demand [10]. For example, firms pursue green technology innovations to obtain market competitiveness. However, green innovation is characterized by large capital investment, long R&D cycles, and high uncertainty [9], and only continuous R&D investment can ensure the smooth progress of enterprise green innovation [6].

Current research on consumers' influence on corporate green innovation analyzes how consumer environmental preferences can promote green technological innovation by facilitating firms' R&D investment in two main ways. On the one hand, the consumer attaches increasing importance to environmental issues, and for heavily polluting enterprises with serious environmental pollution, the public's demand for environmental protection can motivate local governments to enforce more environmental protection laws and regulations, improve industrial structure, and increase the investment in environmental governance [23,27]. To a certain extent, this alleviates the financing constraints of heavily polluting enterprises in environmental protection investment and green innovation and encourages heavily polluting enterprises to increase clean production and green research and development intensity [2,27]; this is in an effort to improve the efficiency of resource use and the ability to control pollution, as well as to achieve green emissions and green transformation and upgrading.

On the other hand, with the prevalence of the green consumption concept, consumers will resist products produced by heavily polluting enterprises that are ecologically damaging or consume large amounts of energy, forming a soft constraint on heavily polluting enterprises [25]. In order to meet market demand and enhance competitiveness in market competition, heavily polluting enterprises will increase green R&D investment and technological innovation to produce greener products. Moreover, due to the long and difficult implementation chain of green innovation, the effectiveness of innovation often has a time lag, and the R&D investment from the front-end of innovation is more likely to reflect

the impact of consumers' environmental preferences on the green innovation of heavily polluting enterprises [26]. Thus, we put forward the following hypothesis:

Hypothesis 2. *Consumer environmental preferences can promote green innovation in heavily polluting firms by stimulating R&D investment in heavily polluting firms.*

2.2.2. Environmental Protection Concept

Signaling theory, proposed by A. M. Spence in 1973, suggests that signaling refers to the transmission of precise information about the value or quality of a good through observable consumer behavior, and the production of goods is influenced by the information. When consumers are more willing to choose green products than normal products and are willing to pay higher prices for them [14,15], according to signaling theory, enterprises are impacted by this market signal [5]. Some studies have found that enterprises set up a green development strategy and strengthen their environmental protection concept. The enterprise's environmental protection concept promotes the enterprise's green technology innovation [25,28].

For heavily polluting enterprises, because daily production activities may produce environmental pollution, the company will face more public opinion pressure and social attention. On the one hand, in order to win public recognition, attract benign attention and reports, create a good corporate image, and enhance the social status of the company [1,8]. On the other hand, they may do so in order to attract potential consumers [23], producing green products that meet the market demand so as to obtain greater economic benefits and realize their own green sustainable development. Heavily polluting enterprises will take the initiative to establish environmental protection concepts and integrate environmental protection concepts into the company's production activities, which drives the enterprises to adopt green innovation behaviors on their own [28]. Heavily polluting enterprises with high-quality environmental protection concepts will practice environmental protection concepts in all chains of production work and truly internalize environmental protection concepts that serve as the internal drive of the company's innovation activities [25]. Thus, we put forward the following hypothesis:

Hypothesis 3. *Consumer environmental preferences can promote green innovation in heavily polluting firms by reinforcing their environmental concepts and encouraging them to develop an environmentally friendly image.*

3. Methodology

3.1. Samples and Data Collection

During our research, we used the data of Chinese A-share listed enterprises in heavily polluting industries from 2011 to 2022 as a sample (adopting the 16 categories of industries found in the Guidelines for Disclosure of Environmental Information of Listed Companies, published by the former Ministry of Environmental Protection of China in 2010, as the heavily polluting industries to screen and match the enterprises, excluding ST and PT samples and financial listed companies, as well as some samples with missing data) to study the influence of consumers' environmental preference on the green technological innovation of heavily polluting enterprises, including those working with chemicals, petrochemicals, building materials, paper, etc. In this paper, the green patent data of listed companies come from the CNRDS (China Research Data Service Platform), and based on the research of Liu et al. [25], we match them with the "Green List of International Patent Classification" issued by the World Intellectual Property Organization (WIPO) in 2010. Based on the matching results, we categorize listed companies' patents into green patents (green invention patents and green utility model patents) and non-green patents (non-green invention patents and non-green utility model patents). The rest of the companies' characteristic data mainly come from the Cathay Pacific database. After matching the above data, we finally obtained 59,760 annual observations for 415 companies.

3.2. Variables

3.2.1. Dependent Variable: Green Technology Innovation

This paper uses the total number of green patent applications of listed companies in China's A-share heavily polluting industries in the year as the core indicator for measuring enterprises' green technological innovation. Specifically, this study sums up the number of green invention patent applications and the number of green utility model patent applications to obtain the total amount of green innovation. This study defines the number of green invention patent applications and the number of green utility model patent applications as substantive green innovation and strategic green innovation, respectively, to compare and measure the quality of the green innovation of heavily polluting enterprises. Generally speaking, substantive green innovation emphasizes the quality of innovation, which is more difficult and risky to realize, and can also bring great economic and environmental benefits when successful; on the contrary, the strategic green innovation of utility models requires relatively low R&D capability, and the contribution of output results is relatively small. Due to the right-skewed distribution problem of the number of green patent applications, this paper adopts a natural logarithmic approach by adding one to the number of applications.

3.2.2. Independent Variable: Consumer Environmental Preferences

Consumer preference is a subjective evaluation that is difficult to quantify. The NEP scale is a measure of consumer environmental preferences [21]. It was introduced to China relatively late. Dayong Hong introduced the New Ecological Paradigm (NEP) scale into the China General Social Survey in 2003. However, due to the limitations of the questionnaire method, such as high subjectivity, high measurement cost, and difficulty in obtaining data, there is no consensus among scholars in China on the use of the questionnaire method as a tool to measure environmental concern.

In addition to the questionnaire method, another method to measure consumers' environmental preferences is the Revealed Preference method. According to the theory of Revealed Preference proposed by P. Samuelson in 1948, the consumer's purchasing behavior under certain price conditions reveals or shows his inherent preference tendency. Thus, we can infer the consumer's environmental preferences based on the consumer's actual purchasing behavior. Ito and Zhang [29] used micro-transaction data on the purchase of air purifiers by urban residents for the first time and found that the marginal willingness to pay for clean air for urban residents in China is USD 1.52. However, due to the limitation of the availability of micro-transaction data, there are few articles adopting this method to study the environmental preferences of consumers, and more scholars use environmental pollution search data instead of micro-transaction data to conduct research [23,30]. In order to study the impact of environmental preferences and market competition on firms' green innovation, Zheng et al. [30] searched "Baidu" with the keyword "environment" and calculated environmental pollution search data to measure consumer environmental preferences, and they found that environmental preferences and market competition complement each other to promote corporate green innovation. Therefore, this paper improves the rationality of consumer preference measurement from the perspectives of public environmental concerns and public environmental demands.

The first perspective is that of environmental concern. With the development of the Internet, Internet search data that record the behavior of Internet users can promptly capture the attention of market players to specific events, reflecting their preferences and behavioral intentions. Thus, we know that environmental concern is an important manifestation of consumer environmental preferences. Therefore, this paper refers to the study of Wu et al. [31] and adopts the "Baidu" environmental pollution search index in each province to measure consumer environmental preferences. The "Baidu" environmental pollution search index is categorized by search channel into PC search index, mobile search index, and total search index, where the total search index is equal to the sum of the PC search index and mobile search index. The "Baidu" environmental pollution search index is ob-

tained for 30 provinces and regions from 2011 to 2022. The source of data is the air-quality online analysis and testing platform.

The second perspective is that of environmental petitions and complaints. The public is the supervisor of the enterprise's green governance. Once the production of local heavily polluting enterprises brings about environmental pollution problems, affecting the ecological environment and people's lives, the public will often express their demands for environmental governance through letters, telephone reports, petitions, protests, etc. Thus, the data on public environmental protection demands can also directly reflect the environmental preferences of consumers. Currently, scholars use both single indicators [23] and composite indicators [30] to measure public environmental demands. In order to cover the information comprehensively, this paper selects three indicators—the total number of environmental letters; batches of visits; and the number of visitors received by provinces and regions in one year—from the China Environmental Yearbook [30], utilizes principal component analysis to compute a composite index of the public's environmental appeals to assess consumers' environmental preferences, and conducts a robustness test. Given the availability of data, data for 30 provinces were finally obtained for 2011–2019.

3.2.3. Control Variables

In order to control other indicators of economic characteristics affecting corporate green innovation, this paper introduces relevant control variables with reference to the existing literature: enterprise size (Size), expressed as the logarithm of the total assets of the enterprise; enterprise debt ratio (Lev), expressed as the total liabilities divided by the total assets; net profitability (ROA), expressed as the net profit divided by the total assets; gross operating profit margin (GOP), expressed as the operating revenue minus the operating costs divided by the operating revenue; cash holding ratio (Cash), expressed as corporate money funds divided by total assets; debt to equity Ratio (DE), expressed as the ratio between liabilities and owner's equity of a company; and corporate age (Age), expressed by subtracting 2022 from the year of the company's establishment. The sources of the data are the CSMAR database and the Wind database.

The descriptive statistics of the main variables are shown in Table 1. Among them, the minimum value of the green patent application variable is 0, the maximum value is 6.91, and the standard deviation is 0.93, indicating that there is a large difference in the level of green technological innovation among heavy polluters and there is still much room for development. The standard deviation of the "Baidu" environmental pollution search index is 0.40, indicating that there are large differences in public environmental preferences among provinces in different years. The small amount of data for the public environmental claims index is due to the fact that only data from 2011–2019 were obtained. However, the standard deviation is 2.01, which also indicates that there are large differences in consumer environmental preferences.

3.3. Model Construction

The purpose of this paper is to study the impact of consumer environmental preferences on the level of green technological innovation of heavily polluting enterprises. Due to the obvious differences in individual characteristics of enterprises and the many factors affecting the green technological innovation of enterprises, this paper constructs a multidimensional fixed-effects model to minimize the bias caused by the omitted variables on the estimation results. Based on the fixed-effects model controlling for industry and time by Liu et al. [25], this paper adds province fixed effects and constructs a baseline regression model to examine the impact of consumer environmental preferences on the green innovation of heavily polluting enterprises. The specific model is as follows:

$$Innovation_{i,j,k,t} = \gamma_0 + \gamma_1 Preference_{k,t} + \gamma_2 Controls_{i,j,k,t} + \mu_j + \mu_k + \mu_t + \varepsilon_{i,j,k,t} \quad (1)$$

The subscripts i, j, k, t in Model (1) indicates enterprise, industry, province, and year, respectively. $Innovation_{i,j,k,t}$ indicates firms' green innovation, measured by the number of

green patent applications filed by firms in the year. Specifically, it contains the total number of green patent applications of company i in year t (Total), the number of green invention patent applications (Inva), and the number of green utility model patent applications (Uma). $Preference_{k,t}$ is the core explanatory variable—consumer environmental preferences; $Controls_{i,j,k,t}$ is a set of control variables; μ_j , μ_k , μ_t indicates industry, province, and time fixed effects, respectively; and $\varepsilon_{i,j,k,t}$ indicates the random error term of the model. All regressions are clustered at the firm level.

Table 1. Descriptive statistical analysis.

	Variables	Abridge	Obs	Mean	Std. Dev.	Min	Max
Dependent variable	Total number of green patent applications	Total	4980	0.49	0.93	0	6.91
	Green invention patent applications	Inva	4980	0.34	0.78	0	6.75
	Green utility patent applications	Uma	4980	0.29	0.69	0	5.59
	Total number of green patents granted	Total_1	4980	0.41	0.83	0	6.87
	Green invention patent grants	Inva_1	4980	0.20	0.60	0	6.70
	Green utility patent grants	Uma_1	4980	0.29	0.70	0	5.69
Independent variable	“Baidu” environmental pollution search index	Preference	4980	4.76	0.40	1.36	5.37
	Public environmental protection claims index	Public	3479	9.74	2.01	3.93	14.93
Mediator variables	Enterprise R&D investment	R&D invest	4329	17.96	1.80	7.55	24.08
	Enterprise environmental concept word frequency	Concept	4387	1.44	0.97	0	5.38
Control variables	Asset-liability ratio	Lev	4980	0.48	0.22	0.01	3.26
	Net asset profit margin	ROA	4980	0.03	0.09	−1.23	1.53
	Gross profit margin	GOP	4980	0.20	0.14	−2.23	0.91
	Debt-to-equity market value ratio	DE	4892	0.36	0.22	0	0.90
	Cash ratio	Cash	4980	0.61	1.64	0	67.34
	Firm age	Age	4980	25.20	4.73	14.00	47.00
	Firm size	Size	4980	22.75	1.44	19.07	28.64

4. Results

4.1. Benchmark Regression Analysis

After Hausman’s test, this paper chooses a fixed-effects model to estimate the benchmark model, controlling for time, industry, and province. The regression results in Table 2 show the impact of consumer environmental preference on the green innovation of heavily polluting firms. Without considering other influencing factors, the regression coefficient of environmental preference can be found through column (1) to be 0.483, which is significant at the 1% statistical level, indicating that the rise in environmental preference significantly promotes the green innovation of heavily polluting enterprises. This conclusion is consistent with previous studies [13,30].

Further, from columns (2) and (3), we observe that the regression coefficient of environmental preference and green invention patent applications is 0.249, which is significant at the 5% statistical level; moreover, the regression coefficient of environmental preference and green utility model patent applications is $0.392 > 0.249$, which is significant at the 1% statistical level. This indicates that consumer environmental preferences promote both the substantive and strategic green innovation of heavily polluting enterprises and the promoting effect on strategic green innovation is greater than on substantive green innovation. This finding is not reflected in previous studies [13,30].

Columns (4) to (6) add some control variables. After considering other influencing factors, the positive driving effect of consumers’ environmental preference on the green technological innovation of heavily polluting enterprises is still significantly positive. As can be seen from column (4), every increase of 1 unit in consumer environmental preference will have a positive promoting effect of 0.482 units in the green technological innovation of heavily polluting enterprises. Hypothesis 1 is verified.

Table 2. Regression results of benchmark regression analysis.

Variables	(1) Total	(2) Inva	(3) Uma	(4) Total	(5) Inva	(6) Uma
Preference	0.483 *** (3.14)	0.249 ** (1.96)	0.392 *** (3.20)	0.482 *** (3.09)	0.261 ** (2.03)	0.373 *** (3.01)
Size	-	-	-	0.197 *** (10.00)	0.160 *** (9.73)	0.127 *** (8.53)
ROA	-	-	-	0.019 (0.14)	0.081 (0.71)	-0.051 (-0.47)
GOP	-	-	-	-0.178 (-1.66)	-0.183 ** (-2.05)	-0.139 (-1.65)
Cash	-	-	-	0.004 (0.71)	0.003 (0.61)	0.002 (0.42)
Lev	-	-	-	0.0763 (0.84)	0.033 (0.45)	0.053 (0.75)
DE	-	-	-	-0.594 *** (-5.01)	-0.4178 *** (-4.24)	-0.420 *** (-4.52)
Age	-	-	-	0.0002 (0.03)	0.002 (0.31)	-0.002 (-0.53)
_cons	-1.769 ** (-2.56)	-0.797 (-1.39)	-1.609 *** (-2.94)	-5.884 *** (-7.25)	-4.195 *** (-6.22)	-4.159 ** (-6.56)
R squared	0.3438	0.6169	0.4272	0.4934	0.5545	0.5350
N	4980	4980	4980	4892	4892	4892

*** $p < 0.01$. ** $p < 0.05$.

4.2. Endogenous Issues Analysis

The endogeneity problem of this paper's modeling is mainly reflected in three aspects: bidirectional causality, omitted variables, and sample selection bias. First of all, consumer environmental preferences will promote the green innovation of heavy polluting enterprises, and in turn, heavy polluting enterprises increase their R&D investment and green innovation and produce more green products, which will also stimulate green consumption demand, so there may be a two-way causality problem. In this paper, we adopt the approach of lagging the core explanatory variables in Model (1) by one period to address endogeneity due to bidirectional causality, and the results are shown in column (1) of Table 3. It can be seen that the regression coefficient of environmental preference is significantly positive, indicating that the conclusion obtained from the benchmark regression is relatively robust. Considering the existence of a time lag in the invention and creation of green patents, this paper again analyzes the core explanatory variables using the core explanatory variables lagged by two periods, and the results are shown in column (2) of Table 3. The remains consistent with the previous conclusion that environmental preferences can make a sustained and significant contribution to green technology innovation in heavily polluting firms.

Secondly, in the process of setting up the model, it is impossible to list all the explanatory variables affecting the green innovation of enterprises and we must omit variables from the error term. Moreover, the explanatory variables are correlated with the error perturbation term, which leads to the endogeneity problem. However, since consumer environmental preference is a subjective evaluation, it is difficult to obtain reliable exogenous instrumental variables, so this paper uses core explanatory variables lagged by one period to determine instrumental variables [30] and adopts the panel-data model instrumental variables method to reduce the impact of endogeneity. As shown in column (3) of Table 3, the regression coefficients of environmental preferences are significantly positive at the 1% level, and the results are still in line with theoretical expectations. After conducting the weak instrumental variable test and the non-identifiable test, the Cragg–Donald Wald F-statistic and the Kleibergen–Paaprklm statistic indicate that there is no weak instrumental variable and no over-identification.

Finally, due to the difficulty of green technology innovation and other reasons, there exists a significant proportion of firms in the sample with zero green patent applications; in order to reduce the endogeneity problem caused by sample selection bias, this paper adopts the Heckman two-step approach [25]. The first step uses a probit model including

the full sample, which is used to estimate the probability of whether a firm has a green patent application or not, and then calculates the inverse Mills ratio based on the model; the second step re-estimates the regression parameters by treating the inverse Mills ratio as a control variable to correct the sample selection bias. The regression results are shown in column (4) of Table 3—the regression coefficients of environmental preferences remain significantly positive at the 1% level, and the previous results are robust.

Table 3. Regression results for addressing endogeneity.

Variable	Total _{t+1}	Total _{t+2}	IV-FE	Heckman Two-Step
Preference	0.442 ** (2.52)	0.348 * (1.84)	0.252 *** (3.73)	0.557 *** (3.26)
Size	0.210 *** (10.10)	0.202 *** (9.16)	0.081 *** (3.59)	1.268 *** (12.80)
ROA	−0.229 (−1.63)	−0.242 * (−1.68)	0.092 (0.64)	0.757 *** (4.95)
GOP	−0.179 (−1.61)	−0.243 ** (−2.12)	−0.060 (−0.51)	−1.182 *** (−8.35)
Cash	−0.001 (−0.13)	−0.007 (−0.46)	0.0004 (0.03)	−0.008 (−1.30)
Lev	−0.041 (−0.43)	−0.176 * (−1.77)	−0.027 (−0.28)	0.542 *** (5.44)
DE	−0.443 *** (−3.54)	−0.208 (−1.58)	−0.278 ** (−2.27)	−2.498 *** (−11.96)
Age	−0.001 (−0.17)	−0.003 (−0.46)	0.001 (0.21)	−0.003 (−0.57)
_cons	−6.030 *** (−6.18)	−5.275 *** (−5.06)	−2.423 *** (−5.26)	−33.991 *** (−12.79)
Cragg–Donald Wald F statistic			4335.669	
Kleibergen–PaaprLM statistic			322.484 ***	
N	4487	4077	4487	4869
Rsquared	0.4888	0.4691	0.1664	0.5324

*** $p < 0.01$. ** $p < 0.05$. * $p < 0.1$.

4.3. Robustness Test

In order to further verify the reliability of the research findings, this paper conducts a robustness test by replacing the core explanatory variable and the explanatory variable. The core explanatory variable of consumer environmental preference is replaced by the “Baidu” environmental pollution search index or the public environmental protection demand index and regressed on the total number of green innovation patent applications, the number of green invention patent applications, and the number of green utility model patent applications. The results are shown in columns (1)–(3) of Table 4. From column (1), it can be seen that the regression coefficient of environmental preference is 0.026, which is significant at the 1% level; the regression coefficients of environmental preference in columns (2)–(3) are also all significantly positive, verifying the conclusion of the benchmark model.

The explanatory variable “annual green patent applications of heavy polluting enterprises” is replaced by annual green patent grants of the enterprises to validate the conclusion of the previous section. The results are shown in columns (4)–(6) of Table 4. From column (4), it can be seen that the regression coefficient of environmental preference for green patent authorization is significantly positive, which again verifies the conclusion that consumers’ environmental preferences promote the green technological innovation of heavily polluting enterprises. Comparing columns (5) and (6), it can be seen that the regression coefficient of environmental preference on the number of green invention patents granted is insignificant, but the regression coefficient of the number of green utility model patents granted is significantly positive at the 1% level, indicating that environmental preference promotes strategic green innovations more significantly than substantive green innovations; this is similar to the conclusions drawn from the results of the benchmark regression.

Table 4. Regression results of robustness test.

Variables	(1) Total	(2) Inva	(3) Uma	(4) Total_1	(5) Inva_1	(6) Uma_1
Preference	-	-	-	0.234 *	-0.106	0.409 ***
				(1.75)	(-1.13)	(3.29)
Public	0.026 ***	0.015 *	0.021 ***	-	-	-
	(2.74)	(1.96)	(2.90)			
Size	0.233 ***	0.194 ***	0.143 ***	0.165 ***	0.105 ***	0.126 ***
	(9.77)	(9.69)	(8.02)	(9.59)	(8.60)	(8.39)
GOP	-0.225 *	-0.250 **	-0.014	-0.148	-0.069	-0.175 **
	(-1.69)	(-2.24)	(-1.39)	(-1.60)	(-1.06)	(-2.07)
DE	-0.711 ***	-0.549 ***	-0.450 ***	-0.344 ***	-0.199 ***	-0.291 ***
	(-5.07)	(-4.67)	(-4.15)	(-3.36)	(-2.76)	(-3.12)
ROA	0.040	0.122	-0.111	-0.129	-0.096	-0.075
	(0.22)	(0.80)	(-0.78)	(-1.09)	(-1.15)	(-0.69)
Cash	0.008	0.005	0.004	0.003	0.002	-0.0002
	(0.89)	(0.68)	(0.61)	(0.49)	(0.69)	(-0.06)
Lev	0.136	0.082	0.053	-0.046	0.007 (0.13)	-0.067
	(1.31)	(0.96)	(0.66)	(-0.59)		(-0.94)
Age	-0.004	-0.002	-0.005	-0.007	-0.005	-0.003
	(-0.67)	(-0.32)	(-1.13)	(-1.21)	(-1.32)	(-0.66)
_cons	-4.572 ***	-3.782 ***	-2.871 ***	-4.027 ***	-0.864	-4.231 ***
	(-8.25)	(-8.12)	(-7.01)	(-5.65)	(-1.48)	(-6.55)
N	3392	3392	3392	4892	4487	4892
R squared	0.4886	0.4978	0.5231	0.4930	0.4663	0.5227

*** $p < 0.01$. ** $p < 0.05$. * $p < 0.1$.

5. Further Analysis

5.1. Mediating Mechanism Test

Based on the mechanism analysis in the previous section, this paper proposes that consumer environmental preference mainly realizes the promotion of green technological innovation of heavily polluting enterprises through promoting enterprise innovation input and strengthening the enterprise environmental protection concept. The following mediation model is constructed to explore the mechanisms of innovation input and the environmental protection concept. Model (2) verifies the effect of consumer environmental preference on enterprises' green technological innovation; Model (3) verifies the effect of consumer environmental preference on mediator variables; and Model (4) puts both consumer environmental preference and mediator variables into the equation at the same time to verify the effect on enterprises' green technological innovation.

$$Innovation_{i,j,k,t} = \gamma_0 + \gamma_1 Preference_{k,t} + \gamma_2 Controls_{i,j,k,t} + \mu_j + \mu_k + \mu_t + \varepsilon_{i,j,k,t} \quad (2)$$

$$Mediator_{i,j,k,t} = \beta_0 + \beta_1 Preference_{k,t} + \beta_2 Controls_{i,j,k,t} + \mu_j + \mu_k + \mu_t + \varepsilon_{i,j,k,t}' \quad (3)$$

$$Innovation_{i,j,k,t} = \delta_0 + \delta_1 Preference_{k,t} + \delta_2 Mediator_{i,j,k,t} + \delta_3 Controls_{i,j,k,t} + \mu_j + \mu_k + \mu_t + \varepsilon_{i,j,k,t}'' \quad (4)$$

In Model (3), the mediating variables are R&D investment and the environmental concept. R&D investment is represented by the natural logarithm of the annual R&D expenditures of enterprises. The mediating variable of the environmental concept is explored using the text analysis method, which selects a series of keywords based on three dimensions—perception of green competitive advantage, perception of corporate social responsibility, and perception of external environmental pressure—and determines the environmental protection concepts of heavily polluting enterprises through the frequency of the above words in the annual financial reports, social responsibility reports, and environmental reports of heavily polluting enterprises in the period of 2011–2022. The number of times that these words appear in the annual financial reports, social responsibility reports, and environmental reports are also noted to determine the environmental protection concept of heavily polluting enterprises. The higher the frequency of the key-

words of the environmental protection concept, the stronger the company's environmental protection concept.

5.1.1. The Mediating Role of R&D Investment

Columns (1)–(2) of Table 5 report the results of testing the R&D investment mechanism. The relationship between environmental preferences and R&D investment is first explored by regressing Model (3). The regression results from column (1) show that the regression coefficient of environmental preference and innovation R&D investment is 0.890, which is significant at the 1% level, indicating that the rise in consumer preference for green products influences the production of products by heavily polluting enterprises from the perspective of market demand, prompting enterprises to increase innovation R&D investment, improve their production technology, eliminate high-pollution and high-energy-consumption production lines, and produce more green and environmentally friendly products. In turn, this is conducive to enhancing the competitiveness of enterprises and maximizing profits. Further, the environmental preference and the mediating variable of R&D investment are both included in the model to explore the mediating effect, and the regression of Model (4) is carried out.

Table 5. Regression results of mediating mechanism test.

Variables	(1) R&D Invest	(2) Total	(3) Concept	(4) Total
Preference	0.890 *** (12.24)	−0.008 (−0.19)	0.203 *** (5.21)	0.166 *** (4.33)
R&D invest	-	0.198 *** (21.30)	-	-
concept	-	-	-	0.065 *** (4.06)
Size	0.435 *** (12.18)	0.010 (0.47)	0.011 (0.51)	0.095 *** 4.61
GOP	−1.527 *** (−6.29)	−0.099 (−0.72)	−0.652 *** (−4.78)	−0.442 *** (−3.29)
DE	4.383 *** (18.50)	0.750 *** (5.36)	1.519 *** (10.71)	1.548 *** (10.94)
ROA	0.734 (1.07)	0.673 * (1.74)	0.398 (1.06)	0.556 (1.51)
Cash	−0.118 *** (−5.47)	0.006 (0.48)	−0.027 *** (−2.88)	−0.009 (−1.01)
Lev	−1.750 *** (−6.49)	−0.139 (−0.91)	−0.842 *** (−5.35)	−0.581 *** (−3.75)
Age	−0.046 *** (−8.13)	0.001 (0.29)	−0.002 (−0.64)	−0.001 *** (−2.90)
_cons	16.097 *** (37.54)	−3.186 *** (−11.19)	0.575 ** (2.44)	−0.005 (−0.02)
N	3715	3715	3770	3770
R squared	0.1986	0.1699	0.0606	0.0699
Sobel statistic	10.61 ***	10.61 ***	3.202 ***	3.202 ***

*** $p < 0.01$. ** $p < 0.05$. * $p < 0.1$.

The regression results from column (2) of Table 5 show that the regression coefficient of R&D investment is 0.198, which is significant at the 1% level, indicating that the increase in R&D investment by heavily polluting enterprises promotes the green technological innovation of enterprises. After the Sobel test, the Z-value result is significant at the 1% level, indicating that the mediating effect of “consumer environmental preference $\uparrow \rightarrow$ enterprise R&D investment $\uparrow \rightarrow$ green technology innovation \uparrow ” exists significantly. This conclusion is consistent with previous studies [6,25]. Hypothesis 2 is verified.

5.1.2. The Mediating Role of the Environmental Concept

Columns (3)–(4) of Table 5 show the results of testing the environmental concept mechanism. The relationship between environmental preferences and the corporate environmental concept is first explored by regressing Model (3). The regression results from

column (3) show that the regression coefficient of environmental preference and the environmental protection philosophy is 0.203, which is significant at the 1% level, indicating that with the increase in consumers' environmental protection awareness and their desire for a better life, they will resist products produced by companies with detrimental environmental behaviors, thus forming a soft constraint on the heavily polluting companies. In order to win public recognition, establish a good image of being environmentally friendly, and attract potential consumer groups, heavily polluting companies are prompted to take the initiative to form an environmentally friendly concept. We further explored the mediating effect through the regression of Model (4), and from the regression results of column (4), we can see that the regression coefficients of environmental preference and the environmental protection concept are both significantly positive at the 1% level. After the Sobel test, the Z-value is still significant at the 1% level, which indicates that the mediating effect of "consumer environmental preference $\uparrow \rightarrow$ enterprise environmental concept $\uparrow \rightarrow$ green technology innovation \uparrow " exists significantly. This conclusion also supports previous studies [27,28]. Hypothesis 3 is verified.

In conclusion, the mediating variables of R&D investment and the environmental concept are reasonable, and consumer environmental preferences can realize the promotion of the green technological innovation of heavily polluting enterprises by stimulating innovative R&D investment and enhancing the environmental concept of firms.

5.2. Heterogeneity Analysis

In this paper, we investigate the effects of consumers' environmental preferences on the green technological innovation of heavily polluting firms in different contexts in terms of the level of regional marketization development, the strength of government environmental governance, firm size, and property attributes.

5.2.1. Level of Marketization

Market orientation can provide a guarantee for enterprises to implement green innovation [3]; however, the existence of varying degrees of ethical misconduct in the transition process of China's market economy (e.g., counterfeit goods, false advertisements) makes the process of enterprise green innovation difficult, which shows that a sound and perfect market is conducive to creating a favorable environment for the green innovation activities of enterprises. Zheng et al. [30] adopted the marketization index to measure the marketization level and found a higher level of marketization in the eastern region than in the central and western regions of China. This paper also adopts the marketization index to measure the marketization level. According to the median of the marketization index for grouping, the sample is divided into two groups—high and low marketization levels—for group regression, and the regression results are shown in Table 6.

As can be seen from columns (1) and (2) of Table 6, the coefficients of preference are significantly positive, and the preference coefficients of the enterprises with high levels of marketization in their regions are significantly higher than those of the enterprises with low levels of marketization in their regions ($0.568 > 0.385$), which indicates that in regions with a high level of marketization, the promotion effect of consumer environmental preference on enterprises' green technology innovation is more obvious. The reason may be that in regions with a high level of marketization, the better business environment and market competition atmosphere have positive incentives for the green technology innovation of heavy-polluting enterprises.

5.2.2. Intensity of Government Environmental Regulation

In the context of institutional culture with Chinese characteristics, the government always plays an important role in environmental governance; therefore, the green innovation behavior of enterprises is inevitably affected by the government's environmental regulation. In this paper, the word frequencies of keywords related to environmental regulation in provincial government work reports were counted separately; Python 3.7 was utilized

to process the word division of each province's government work report [27]. The word frequency sum of keywords related to environmental regulation in the government work reports of each province and region from 2011 to 2022 was used as a proxy variable for the government's environmental-regulation intensity, and the sample was divided into two groups—of high and low environmental-regulation intensity—according to the median of the word frequency sum of environmental-regulation intensity. The effect of consumer environmental preferences on the green technology innovation of enterprises with different environmental-regulation strengths in their regions is compared through group regression, and the regression results are shown in Table 7.

Table 6. Regression results of heterogeneity in the level of marketization.

Variables	(1) High Level of Marketization Total	(2) Low Level of Marketization Total	(3) High Level of Marketization Inva	(4) Low Level of Marketization Inva	(5) High Level of Marketization Uma	(6) Low Level of Marketization Uma
Preference	0.568 *** (2.61)	0.385 * (1.70)	0.152 (0.84)	0.389 ** (2.10)	0.522 *** (3.18)	0.208 (1.14)
Size	0.176 *** (7.60)	0.181 *** (4.77)	0.140 *** (7.16)	0.132 *** (4.47)	0.107 *** (6.26)	0.122 *** (4.05)
GOP	−0.115 (−0.93)	−0.202 (−0.93)	−0.102 ** (−0.99)	−0.204 (−1.18)	−0.116 (−1.20)	−0.046 (−0.26)
DE	−0.548 *** (−3.94)	−0.680 *** (−2.98)	−0.386 *** (−3.33)	−0.387 ** (−2.11)	−0.353 *** (−3.27)	−0.615 *** (−3.37)
ROA	0.041 (0.26)	0.091 (0.33)	0.079 (0.60)	0.204 (0.90)	−0.016 (−0.13)	−0.110 (−0.49)
Cash	0.006 (0.83)	−0.0001 (−0.01)	0.003 (0.45)	0.005 (0.50)	0.003 (0.67)	−0.004 (−0.39)
Lev	0.053 (0.51)	0.363 * (1.95)	0.021 (0.55)	0.192 (1.28)	0.014 (0.18)	0.365 ** (2.45)
Age	0.003 (0.43)	−0.017 (−1.07)	0.004 (0.62)	−0.008 (−0.74)	−0.001 (−0.22)	−0.011 (−0.81)
_cons	−5.886 *** (−5.34)	−4.712 *** (−3.62)	−3.362 *** (−3.66)	−3.977 *** (−3.88)	−4.381 *** (−5.11)	−3.113 *** (−3.00)
N	3723	1169	3723	1169	3723	1169
R squared	0.5190	0.5917	0.5371	0.5966	0.5944	0.5613

*** $p < 0.01$. ** $p < 0.05$. * $p < 0.1$.

From columns (1) and (2) of Table 7, it can be seen that the preference coefficients are significantly positive, and the preference coefficients in regions with low environmental-regulation intensity are significantly higher than the preference coefficients in regions with high environmental-regulation intensity ($0.632 > 0.309$), which indicates that for firms located in regions with low environmental-regulation intensity, the impact of environmental preference on their green technological innovation is greater, while for firms located in regions with high environmental-regulation intensity, the impact of environmental preference on their green technological innovation is smaller. The reason may be that in regions with strong environmental regulation, higher environmental administrative penalties increase the cost of heavy polluters, which, in turn, inhibits the technological innovation of heavy polluters.

5.2.3. Enterprise Size

Enterprise size is an important factor affecting the innovation capacity of enterprises. Large enterprises have advantages in terms of capital, personnel, and technological reserves, and have a higher capacity to innovate, but they also have problems such as redundancy of institutions and personnel and are less motivated to innovate and less efficient at doing so [6]. Small- and medium-sized enterprises' innovation, on the other hand, is more constrained by the financial problems of innovation. Despite the high willingness and efficiency to innovate, however, due to financing difficulties and other reasons, SMEs generally have the problem of insufficient R&D investment to constrain innovation [32]. In this paper,

enterprises are categorized into large enterprises and small- and medium-sized enterprises based on the median total assets of the sample enterprises and regressed separately.

Table 7. Regression results of heterogeneity in the intensity of government environmental regulation.

Variables	(1) High Environmental- Regulation Intensity Total	(2) Low Environmental- Regulation Intensity Total	(3) High Environmental- Regulation Intensity Inva	(4) Low Environmental- Regulation Intensity Inva	(5) High Environmental- Regulation Intensity Uma	(6) Low Environmental- Regulation Intensity Uma
Preference	0.309 * (1.81)	0.632 *** (2.66)	0.211 (1.49)	0.292 (1.49)	0.227 * (1.79)	0.448 ** (2.27)
Size	0.113 *** (4.33)	0.223 *** (7.99)	0.078 *** (3.62)	0.183 *** (7.78)	0.078 *** (4.28)	0.130 *** (6.02)
GOP	−0.061 (−0.41)	−0.099 (−0.70)	−0.084 (−0.68)	−0.070 (−0.59)	−0.076 (−0.71)	−0.127 (−1.10)
DE	−0.343 ** (−2.36)	−0.735 *** (−4.08)	−0.150 (−1.24)	−0.598 *** (−4.00)	−0.325 *** (−3.05)	−0.402 *** (−2.73)
ROA	0.044 (0.26)	−0.028 (−0.14)	0.107 (0.76)	0.036 (0.22)	−0.007 (−0.06)	−0.064 (−0.39)
Cash	0.002 (0.30)	0.004 (0.58)	0.001 (0.25)	0.004 (0.57)	0.002 (0.32)	0.001 (0.17)
Lev	0.054 (0.52)	0.042 (0.29)	−0.018 (−0.20)	0.070 (0.59)	0.115 (1.51)	−0.081 (−0.69)
Age	0.003 (0.39)	−0.002 (−0.23)	0.003 (0.58)	−0.002 (−0.23)	0.000 (0.04)	−0.001 (−0.11)
_cons	−3.635 *** (−3.92)	−7.087 *** (−5.82)	−2.579 *** (−3.34)	−4.833 *** (−4.77)	−2.590 *** (−3.88)	−4.511 *** (−4.55)
N	2863	2493	2863	2493	2863	2493
R squared	0.2484	0.6509	0.3130	0.6661	0.2056	0.6800

*** $p < 0.01$. ** $p < 0.05$. * $p < 0.1$.

The results are shown in Table 8: the preference coefficient of large enterprises is significantly positive at the 1% level, while that of small- and medium-sized enterprises is not significant. This indicates that consumer environmental preference has a more significant role in promoting green technology innovation in large firms. A possible explanation for this is that large firms are less likely to be constrained by financing constraints for innovation than SMEs because they have the ability to comprehensively utilize a variety of financing channels.

5.2.4. Corporate Property

Based on the political perspective, state-owned enterprises are generally subject to strict government control and bear considerable social responsibility, with both economic and political attributes [2]. As the need for sustainable development is increasingly emphasized, SOEs have also become an important tool for the government to promote high-quality development. Therefore, compared with private enterprises, SOEs may be subject to stricter environmental regulatory pressures and market supervision, SOEs generally have more serious principal-agent problems, innovation projects have higher sunk costs and the possibility of R&D failures, and the management is less willing to take innovation risks due to considerations such as their own promotion pressures and political factors [32]. Based on the different nature of property rights, this paper divides the sample enterprises into two groups: state-owned enterprises and private enterprises, and conducts regression separately. The regression results are shown in Table 9.

As can be seen from columns (1) and (2), the preference coefficient of private enterprises is significantly positive at the 5% level, while the preference coefficient of state-owned enterprises is not significant. This suggests that consumer environmental preference has a more significant role in promoting green technology innovation in private enterprises. A possible explanation is that in the face of market competition, in order to maintain competi-

tive advantage and expand market share, private enterprises have a higher willingness to innovate compared with state-owned enterprises.

Table 8. Regression results of heterogeneity in enterprise size.

Variables	(1) Large Enterprises Total	(2) Small- and Medium-Sized Enterprises Total	(3) Large Enterprises Inva	(4) Small- and Medium-Sized Enterprises Inva	(5) Large Enterprises Uma	(6) Small- and Medium-Sized Enterprises Uma
Preference	1.296 *** (3.87)	0.093 (0.65)	0.881 *** (3.14)	−0.018 (−0.16)	0.810 *** (2.88)	0.138 (1.37)
Size	0.387 *** (9.61)	0.120 *** (4.36)	0.321 *** (9.38)	0.093 *** (4.19)	0.252 *** (8.42)	0.051 *** (2.72)
GOP	−0.560 ** (−2.47)	0.096 (0.89)	−0.475 ** (−2.49)	0.038 (0.44)	−0.367 ** (−2.03)	0.021 (0.28)
DE	−0.695 *** (−3.34)	−0.435 *** (−3.00)	−0.432 ** (−2.47)	−0.356 *** (−3.07)	−0.568 *** (−3.32)	−0.165 (−1.64)
ROA	0.548 (1.48)	−0.049 (−0.43)	0.477 (1.54)	0.014 (0.15)	0.149 (0.49)	−0.041 (−0.52)
Cash	−0.047 (−1.13)	0.001 (0.13)	−0.034 (−0.98)	−0.000 (−0.12)	−0.053 (−1.54)	0.001 (0.23)
Lev	0.183 (0.80)	0.139 * (1.66)	−0.033 (−0.17)	0.134 ** (2.00)	0.151 (0.82)	0.035 (0.59)
Age	0.009 (0.87)	−0.008 (−1.37)	0.009 (1.06)	−0.004 (−0.88)	0.000 (0.06)	−0.005 (−1.62)
_cons	−14.044 *** (−7.81)	−2.569 *** (−2.98)	−10.808 *** (−7.14)	−1.611 ** (−2.33)	−8.967 *** (−6.19)	−1.512 ** (−2.54)
N	2459	2433	2459	2433	2459	2433
R squared	0.4780	0.1755	0.4790	0.1690	0.5370	0.1463

*** $p < 0.01$. ** $p < 0.05$. * $p < 0.1$.

Table 9. Regression results of heterogeneity in corporate property.

Variables	(1) State-Owned Enterprises Total	(2) Private Enterprises Total	(3) State-Owned Enterprises Inva	(4) Private Enterprises Inva	(5) State-Owned Enterprises Uma	(6) Private Enterprises Uma
Preference	0.319 (1.37)	0.465 ** (2.44)	0.145 (0.74)	0.241 (1.59)	0.346 * (1.80)	0.286 ** (2.05)
Size	0.262 *** (10.21)	0.134 *** (5.27)	0.218 *** (10.15)	0.104 *** (5.05)	0.181 *** (9.43)	0.058 *** (3.22)
GOP	−0.361 ** (−2.15)	0.021 (0.17)	−0.341 ** (−2.42)	0.025 (0.25)	−0.235 * (−1.76)	−0.028 (−0.31)
DE	−0.768 *** (−4.72)	−0.560 *** (−3.57)	−0.577 *** (−4.21)	−0.431 *** (−3.44)	−0.617 *** (−4.71)	−0.257 ** (−2.26)
ROA	0.067 (0.29)	−0.013 (−0.09)	0.151 (0.77)	0.025 (0.22)	−0.086 (−0.45)	−0.023 (−0.22)
Cash	−0.010 (−0.55)	0.001 (0.19)	−0.004 (−0.26)	−0.000 (−0.04)	−0.012 (−0.84)	0.001 (0.18)
Lev	0.153 (1.17)	0.130 (1.14)	0.105 (0.95)	0.141 (1.55)	0.198 (0.98)	0.017 (0.21)
Age	−0.004 (−0.47)	0.002 (0.23)	0.001 (0.08)	0.003 (0.45)	−0.005 (−0.97)	−0.003 (−0.64)
_cons	−6.433 *** (−5.44)	−4.693 *** (−4.65)	−4.919 *** (−4.95)	−3.154 *** (−3.90)	−5.006 *** (−5.25)	−2.341 *** (−3.21)
N	2915	2269	2915	2269	2915	2269
R squared	0.4966	0.4125	0.5044	0.3412	0.5275	0.4606

*** $p < 0.01$. ** $p < 0.05$. * $p < 0.1$.

6. Discussion

The questions this paper attempts to study are: Can consumer environmental preferences promote green technology innovation in heavily polluting firms? What is the influence mechanism? To explore these questions, this paper takes Chinese A-share listed companies in heavily polluting industries from 2011 to 2022 as a sample to study the impact and mechanism of consumers' environmental preferences on the green technological inno-

vation of heavily polluting companies. Based on the theory of Revealed Preference, this paper uses the “Baidu” environmental pollution search index and public environmental protection claims index to measure consumer environmental preference. The theory of Revealed Preference is the basis for measuring the explanatory variables in this paper.

Firstly, the empirical test results show that consumer environmental preference significantly promotes the green technological innovation of heavily polluting enterprises, which is consistent with prior studies [13,30,33]. This paper uses the total number of green patent applications to measure enterprises’ green technological innovation and defines the number of green invention patent applications and the number of green utility model patent applications as substantive green innovation and strategic green innovation, respectively. The regression result shows that consumer environmental preference significantly promotes both substantive green innovation and strategic green innovation, and the promotion effect of environmental preference is more significant for strategic green innovation than for substantive green innovation. The fact that consumer environmental preference imposes a higher influence on strategic green innovation than substantive green innovation is not reflected in previous studies [13,30,33], but the possible reason for this is that strategic green innovation can help firms satisfy the green demands of customers with lower costs, so firms are more willing to undertake strategic green innovation than substantive green innovation [5,34].

We used explanatory variables lagged by one period to calculate the instrumental variables, the panel-data model instrumental variables method to reduce the impact of endogeneity, and the Heckman two-stage model to deal with the endogeneity problem. Then, we replaced the core explanatory variable and the explanatory variable for robustness testing and found that the positive driving effect of consumer environmental preference on the green technological innovation of heavily polluting enterprises is still significantly positive. This shows that the conclusions of this paper are reliable and robust.

In addition, we further study the impact of the mechanism of consumers’ environmental preferences on green technological innovation. Based on stakeholder theory and signaling theory, we use R&D investment and the environmental concept as mediating variables. Stakeholder theory is the theoretical support of the R&D investment mechanism, and signaling theory supports the environmental concept mechanism. The results show that the regression coefficient of environmental preference and innovation R&D investment is significantly positive at the 1% level, and the regression coefficient of R&D investment and green technological innovation is also significantly positive at the 1% level, which indicates that the mediating effect of “consumer environmental preference $\uparrow \rightarrow$ enterprise R&D investment $\uparrow \rightarrow$ green technology innovation \uparrow ” exists significantly. Moreover, the regression coefficient of environmental preference and the environmental concept is significantly positive at the 1% level, and the regression coefficient of environmental concept and green technological innovation is also significantly positive at the 1% level, which indicates that the mediating effect of “consumer environmental preference $\uparrow \rightarrow$ enterprise environmental concept $\uparrow \rightarrow$ green technology innovation \uparrow ” also exists significantly. The conclusions are in harmony with previous research [6,10,25].

Finally, we investigate the effects of consumers’ environmental preferences on the green technological innovation of heavily polluting firms in different contexts in terms of the level of regional marketization development, the strength of government environmental governance, firm size, and property attributes. The heterogeneity analysis shows that consumer environmental preference has a more prominent effect on the promotion of the green innovation of enterprises in regions with a high degree of marketization and a low level of governmental environmental regulation, and there is a more prominent effect on the promotion of large-scale enterprises and private enterprises. The reason may be that in regions with a high level of marketization, the better business environment and market competition atmosphere have positive incentives for the green technology innovation of heavily polluting enterprises [30]. Moreover, strong government environmental regulation causes higher environmental administrative penalties to increase the costs of heavy pol-

luters, which in turn inhibits the technological innovation of heavy polluters [23]. Moreover, large firms are less likely to be constrained by financing constraints for green innovation, and private enterprises have a higher motivation and willingness to innovate [32].

7. Conclusions and Implications

With the concepts of green and low carbon deeply rooted in people's hearts and consumers' concern for environmental protection, green consumption has become a trend. Additionally, green and low-carbon development has become mainstream, which has a non-negligible impact on the production and innovation activities of heavily polluting enterprises. Using the data of companies listed on China's A-share stock market from heavily polluting industries from 2011 to 2022, this paper empirically investigates the impact of consumer environmental preference on green technological innovation. The results indicate that consumer environmental preference significantly promotes the green innovation of firms from heavily polluting industries. Moreover, consumer environmental preference imposes a higher influence on strategic green innovation than substantive green innovation. The mechanism tests suggest that consumer environmental preference encourages green technological innovation by strengthening the environmental protection concept and increasing R&D investment. Finally, we find that increasing consumer environmental preferences have a more prominent effect on the promotion of the green innovation of enterprises in regions with higher levels of marketization and lower government environmental regulation, as well as larger enterprises and private enterprises. Based on these findings, the following implications can be made.

Firstly, we should focus on cultivating consumers' awareness of environmental protection and guiding them to form environmentally friendly consumption preferences. Consumers should be led to favor green products, which would strengthen the market orientation of green technology innovation. The conclusion of this paper shows that the enhancement of consumers' environmental preferences can significantly promote green technological innovation in heavily polluting enterprises. Therefore, the government and policymakers should increase measures focusing on cultivating consumers' environmental awareness and the consumption concept of green consumption to enhance the enthusiasm for enterprises' green innovation from the perspective of market demand, which is conducive to the expansion of domestic demand and the promotion of enterprises' green transformation.

The second suggestion is to further incentivize heavily polluting enterprises to increase their investment in research and development, enhance their independent R&D capabilities, and strengthen their environmental awareness, as well as actively guide them to make green investments. This paper finds that consumer environmental preference encourages green technological innovation by strengthening the environmental protection concept and increasing R&D investment. In the context of green development, enterprises should adjust their investment strategies, give more consideration to increasing R&D and technology introduction, and focus on supporting key core technology research and development. At the same time, enterprises should increase investment in the field of energy saving, emission reduction, and carbon reduction, forming a virtuous cycle of the demand-side and supply-side joint promotion of the green technological innovation of enterprises.

Thirdly, the government should formulate differentiated incentive policies for green technological innovation and realize the precise positioning of policies. When formulating specific green technology innovation incentive policies, the government should take into full consideration the heterogeneity of enterprises and regions, put forward corresponding initiatives in a targeted manner according to the different characteristics of enterprises and regions, and actively encourage and guide heavily polluting enterprises to carry out green technology innovation. This paper finds that increasing consumer environmental preferences have a more prominent effect on the promotion of green innovation for enterprises in regions with higher levels of marketization and lower government environmental regulation, as well as larger enterprises and private enterprises. In regions with a relatively

low degree of marketization, the business environment should be optimized, and market-oriented reforms in less developed regions should be further promoted, so that the domestic macrocycle can be built on the basis of the dynamics of domestic demand. For small- and medium-sized enterprises, resource constraints in terms of green innovation such as financing and talent should be mitigated through a variety of channels and measures, such as capital subsidies and policy support, in order to provide financial, technological, policy, and human resources support for the high-quality development of greening in small- and medium-sized enterprises.

Finally, although this study finds some interesting conclusions and makes contributions to the literature, there are some limitations and room for future research. Using the micro-transaction data on the purchase of green products by consumers to measure consumer environmental preferences may be more direct. This study is also limited due to the omission of several influencing factors, such as market competition and price levels in the industry. Mechanisms of impact could also be explored in depth. Consequently, future researchers are encouraged to take all of these aspects into consideration to expand the existing literature.

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