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The Impact of Carbon Emission Trading Policies on Enterprises' Green Technology Innovation—Evidence from Listed Companies in China

Hong Tian [1], Jiaen Lin [2] and Chunyuan Jiang [1,*]

[1] School of Business and Management, Jilin University, Changchun 130012, China; tianhong2919@163.com
[2] College of Business Administration, Hunan University, Changsha 410012, China; ljecket@163.com
* Correspondence: jiangcy20@mails.jlu.edu.cn

Abstract: At present, the Chinese government has successively launched various policies to control the emission standards of greenhouse gases. As one of the most important standards, carbon emission trading policies were implemented in some provinces and regions in China in 2013, aiming to restrict the carbon emissions of enterprises. However, the government's control of corporate carbon emissions restricts their rapid economic growth to some extent. Enterprises' green technology innovation can be an effective means to ensure the implementation of low-carbon policies and promote sustainable economic growth simultaneously. The Porter hypothesis holds that reasonable environmental regulations can stimulate enterprises' green technology innovation. Based on the Porter hypothesis, this paper examines the impact of China's carbon emission trading policies on local enterprises' green technology innovation from a micro perspective, taking China's listed companies from 2007 to 2020 as samples and adopting the differential method. The differences in the impact of carbon emission trading policies on green technology innovation in the context of different corporate environmental strategies are also studied. Our study found that China's carbon emissions trading policies can effectively stimulate green technology innovation, as carbon emissions trading policies under different environmental strategies have a positive influence on the technical innovation of enterprises and, compared with reactive environmental strategies, promote a greater role for enterprises' proactive environmental strategies. The conclusions of this study not only provide relevant suggestions for the Chinese government to enact environmental regulation policies but also provide references for enterprises to choose appropriate environmental strategies and achieve sustainable development under the constraints of environmental regulation.

Keywords: carbon emission; enterprise green technology innovation; environmental strategy; Porter hypothesis

Citation: Tian, H.; Lin, J.; Jiang, C. The Impact of Carbon Emission Trading Policies on Enterprises' Green Technology Innovation—Evidence from Listed Companies in China. *Sustainability* **2022**, *14*, 7207. https://doi.org/10.3390/su14127207

Academic Editors: Federica Raganati and Paola Ammendola

Received: 21 September 2021
Accepted: 24 April 2022
Published: 13 June 2022

1. Introduction

Since the 21st century, global warming has caused attention to be paid to greenhouse gases. Throughout the history of economic development in various countries, enterprises have constantly pursued profit maximization while ignoring environmental pollution in the process of production and operation, which has affected the sustainable development of human society and increased the social cost of environmental governance. At the micro level, enterprises are sources of pollutant discharge, but they generally lack the initiative to assume the responsibility of environmental governance. Therefore, the governments of various countries have actively sought global governance models to control pollution, and many have issued policies and regulations to restrict the actions of enterprises' that cause environmental pollution. For example, the 1992 United Nations Framework Convention on Climate Change established the UN governance system for tackling climate change and set targets for reducing greenhouse gas emissions. In 1995, the Kyoto Protocol came into force, setting emission reduction targets to be met by 2012 for developed countries. The Paris

Agreement was promulgated in 2015, stipulating that the relevant parties should abide by common guidelines in climate governance.

Due to the external constraints of policies, enterprises must adjust their production activities and increase the additional cost of environmental governance. According to neoclassical economics, rising costs restrict the growth of corporate profits, which is not conducive to the long-term development of enterprises. However, Porter holds different views on this traditional paradigm and proposes that reasonable environmental regulations can stimulate enterprises' green technology innovation to offset the extra environmental costs of enterprises; this is the "Porter hypothesis". Controlling carbon emissions cannot fundamentally solve the problem of greenhouse gas emissions; however, the green technology innovation of enterprises is an effective way to reduce greenhouse gas emissions per unit product and achieve sustainable development. Green technology innovation is an important means for enterprises to reduce the costs associated with long-term emissions. Whether environmental regulation can promote enterprises' green technology innovation has long been a highly debated issue in academic research. In this context, the impact of carbon emission trading policies on enterprises' green technology innovation has become a hot topic of academic research.

China is responsible for a large amount of greenhouse gas emissions, and it is China's unshakable responsibility to reduce greenhouse gas emissions to address climate change. In the context of active global environmental governance, China has made a commitment to achieving peak carbon emissions by 2030 and carbon neutrality by 2060. Under the restrictions of law, greenhouse gases such as carbon dioxide are artificially endowed with commodity properties, and enterprises need to buy their emission rights. The market-based greenhouse gas emission reduction trading system was thus born. Carbon emission trading is one of the economic means recognized internationally as aiding in the realization of the sustainable development of human society. Between 2013 and 2016, China selected Beijing, Shenzhen, Guangdong, Tianjin, Shanghai, Hubei, Chongqing, and Fujian as the locations for the first pilot carbon emission trading policies and then gradually expanded the carbon emission trading market to the whole country, which was expected to be a turning point in global greenhouse gas changes. Currently, China's carbon emission trading policy is still in the pilot stage, and the promotion of this policy across the whole country is an inevitable trend for China in developing green industries in the future. Environmental strategies adopted by enterprises in response to environmental regulations are forward-looking; that is, they actively respond to environmental regulations issued by the government, fulfill environmental responsibilities, and take the lead in improving environmental performance. The other kinds are responsive environmental strategies, which pursue minimum environmental standards and merely fulfill legal obligations.

In conclusion, this study is based on a literature review and an econometric method, looking at the related literature from China and other countries. We combed the literature related to carbon emissions trading policies, green technology innovation, and strategic environments, obtained through the collection of data associated with enterprises, as well as other areas, such as from carbon emissions trading policy pilot areas before and after the issue of the relevant policies and build-panel data. The Stata method of difference-in-difference was used to analyze the relationship between variables, verify the research hypothesis proposed in this paper, and analyze and explain the logic and influence mechanism in the empirical results. Porter's hypothesis was introduced into the research field of environmental strategy, focusing on the impact of carbon emission trading policies on the green technology innovation of enterprises. Additionally, enterprises, divided into two types according to the types of strategies adopted and the differences in the promoting effects of policies on their green technology innovation, are discussed. The heterogeneous effects of different environmental strategies on carbon emission trading policy feedback are analyzed. This paper explores the internal connection between Chinese enterprises' commitment to carbon emission trading policies and green technology innovation so as to test the implementation effect of China's current carbon emission policy.

2. Literature Review

2.1. Carbon Emission Trading Policy

Since the release of the United Nations Framework Convention on Climate Change and the Kyoto Protocol, governments have enacted policies to control carbon emissions in response to global climate change. Climate change is closely related to the increasing concentration of carbon dioxide in the atmosphere, and this affects global temperatures according to IPCC. Artificial carbon pricing and the construction of the carbon emission trading market are considered to be the most economical and effective means by which to control greenhouse gas emissions [1,2]. At present, the development of the carbon emission trading system has allowed certain achievements. Scholars have conducted research on carbon trading markets in different regions. The EU Emissions Trading System (EUETS) is one of the best, most successful, and most studied systems within academic research and now covers 27 member states. Since the launch of the scheme in 2005, the EU has made great contributions to the construction of the global carbon emission trading market, including practical experience in its legal basis, carbon measurement, trading methods, and the operation of the carbon trading market [3]. Ref. [4] reviewed the first phase of the EUETS (2005–2007) as well as the second phase (2008–2012) and elaborated from the perspectives of quota allocation and changes in carbon trading prices. Ref. [5] based their study on five main criteria: stakeholder participation, economic efficiency, market management, revenue management, and environmental effectiveness, which were evaluated according to eight major international carbon emission trading systems, and it was found that institutional learning, administrative prudence, appropriate carbon revenue management, and stakeholder participation were the key factors for the successful implementation of carbon emission trading policies.

China's carbon emission trading policy was implemented late and is still in the pilot state at present. Many scholars have summarized the operation of the carbon emission trading market in developed countries and put forward relevant suggestions for the pilot carbon emission trading policy in China. Some scholars have summarized the construction and practical experience of the international carbon trading market and have analyzed the challenges faced by China in constructing a carbon emission system; they have also proposed consideration of the attributes of carbon in a top-level system design and set up a development-oriented carbon trading market. Other scholars have summarized the two major trends in the development of the global carbon market: globalization and financialization. They have also put forward suggestions to accelerate China's industrial upgrading and transformation so as to realize the transformation of the carbon trading market mechanism from emission reduction (mainly in production industries) to the coordinated operation of multiple departments, including law, finance, and investment. The scientific and reasonable allocation of carbon emission permits is a common problem faced by countries and regions implementing policies. Many Chinese scholars have summarized the quota allocation methods of major international carbon trading centers, providing a reference for the pilot carbon trading system in China. As a major emitter of greenhouse gases, the efficiency of China's carbon trading market has attracted much attention.

At present, the carbon emission trading policies of various countries are complicated, the development of the carbon market is not balanced, the market order is different, and the international carbon trading standards have not been unified. In terms of the common ground between China's carbon emission trading policies and the world's major operating market mechanisms, carbon emission trading policies are mainly aimed at industrial enterprises, controlling their carbon emissions through policies and regulations, and advocating that enterprises need to buy carbon emission rights and take part in the responsibility for environmental governance. In general, China's carbon emission trading system still needs to be continuously supplemented and improved, so the carbon emission trading policy has become an important issue to be explored.

2.2. Enterprises' Green Technology Innovation

Green technology innovation is an effective means by which to ensure high-quality economic development on the premise of harmonious coexistence between humankind and nature. Green technology innovation has significant dual externalities: environmental protection and technological innovation. The concept of green technology innovation has not been unified, and the existing literature expounds on the connotation of green technology innovation from different research perspectives. Ref. [6] elaborated green technology innovation from the perspective of biological co-evolution; stressed the interaction of ecology, society, and institutional systems; and put forward that green technology innovation is the result of the continuous variation in enterprises' technologies and selection under the action of the natural, institutional, and enterprise-internal environments. Ref. [7], on the basis of the life-cycle view, put forward that green technology innovation consists of technology used to minimize the cost of the whole life cycle of products, including innovation in management, raw materials, and process technology. The Organization for Economic Cooperation and Development (OECD) classifies green technology innovation as: green process innovation and green product innovation. The World Intellectual Property Organization (WIPO) technology classification classifies environment-related patents as environmental technologies. The International Patent Classification (IPC) also categorizes green technology innovation patents, including patent subdivisions such as waste disposal and water pollution treatment.

The existing literature on green technology innovation is mainly based on the logic of "external pressure—green innovation behavior—firm performance". Some scholars have discussed the role of public policy in the development and diffusion of green technology in enterprises and have proposed six criteria for policies that can promote green technology innovation. Ref. [8] on the basis of stakeholder theory, discussed the evolution of enterprises' green technology innovation diffusion under the mutual restriction of public consumers, governments, and enterprises. Enterprise performance includes environmental performance and economic performance, which together constitute visual indicators of the green technology innovation achievements of enterprises. This paper discusses the development of external pressure for green innovation and the impact of carbon emission trading policies on enterprises' green technology innovation.

2.3. Enterprises' Environmental Strategies

Ref. [9] taking a natural resource-based view, puts forward that the development of enterprises depends on natural resources and obtains competitive advantages through pollution prevention, product management, and sustainable development. Enterprises' environmental strategies are strategic measures used to deal with the external ecological, environmental pollution in the process of production and operation. Ref. [10] divided environmental strategies into forward-looking strategies and reactive strategies and proposed that proactive environmental strategies could help enterprises take the initiative in responding to environmental regulations issued by the government. Forward-looking environmental strategies require enterprises to have the ability to integrate stakeholder capabilities, high-level learning, and continuous innovation. Actively assuming environmental responsibility encourages enterprises to learn environmental knowledge and skills, accumulate their green knowledge and professional technology-absorption capacity, and improve their green technology innovation performance. Enterprises implementing responsive environmental strategies can fulfill their obligations related to environmental issues, that is, the minimum standards of environmental regulation promulgated by the government. Under the constraints of policies and regulations, enterprises lack the ability to rapidly integrate resources, improve energy utilization efficiency, or control pollution, thus losing the best opportunities for green technology innovation.

3. Theoretical Basis

3.1. Resource Scarcity Theory

Adam Smith and Marshall both argued that resource scarcity leads to higher product prices. Ricardo pointed out that the limited renewable capacity of ecological resources makes natural resources scarce and limits economic growth. With the development of the industrial economy, human society continues to produce greenhouse gases such as carbon dioxide, which breaks the original carbon balance of the ecological circle. Before the carbon trading policy was implemented, companies could emit greenhouse gases at will without any consideration of the environment. After the introduction of the policy, the government restricted the carbon emissions of enterprises, and the carbon emission right became a scarce resource endowed with value. According to resource scarcity theory, the government allocates carbon quotas. Carbon emission rights, as a scarce resource, are allocated by the trading market. Under the influence of the market, the value flows to the highest place and achieves Pareto optimality, thus playing a role in environmental governance and protection. In the case of the scarce resource of carbon emission rights, enterprises can obtain the required resources through other means, such as green technology innovation. Through technological innovation, enterprises can reduce carbon emissions per unit product and obtain carbon emission rights in a disguised way.

3.2. Porter's Hypothesis

Ref. [11] proposed that reasonable environmental regulation can promote enterprises' green technology innovation. Ref. [12] classify Porter's hypothesis into two types: strong and weak. The weak Porter hypothesis emphasizes that although environmental regulation has an impact on technological innovation, the extent and direction of the impact cannot be determined. The Chumbert hypothesis supports the effect of environmental regulation on the competitiveness of enterprises. According to the theory of neoclassical economics, policies and regulations related to environmental protection, to some extent, increase the cost of enterprises and limit the development of enterprises. However, in the context of dynamic competition, the international competitive advantage is often not seen by the companies with low costs and high outputs but by the companies with innovative strength and continuous improvement. Industry standards are one of the main references for the formulation of environmental regulations. Policies and regulations can convey the signs of possible resource inefficiencies and potential technological improvements within enterprises so as to promote enterprises' technological innovation. Environmental regulation itself can stimulate enterprises' sense of social responsibility and promote them to adopt clean production methods, improve waste recovery and disposal technology, and effectively reduce the production and emission of harmful pollutants through green technology innovation.

3.3. Green Technology Innovation Theory

Ref. [11] put forward a theory of technological innovation. Technological innovation changes the production function of enterprises, recombines production factors and conditions for the introduction of a production system, and enables enterprises to achieve excess profits. Ref. [13] first put forward the idea that, on the premise of the sustainable development of humankind and nature, resources can be reasonably allocated through technological innovation, which can reduce the negative impact of human production on the ecosystem. Green technology innovation is not a technological innovation in the traditional sense but integrates the concept of green development into technological innovation, taking into account economic and environmental performance. Compared with general environmental protection measures, green technology innovation, as a forward-looking strategy to fundamentally solve environmental problems, is the key opportunity for enterprises to take advantage of, allowing them to seize the future market and achieve sustainable development by establishing unique technical barriers and cultivating long-term competitive advantages, as well as creating a dual value of the environment and economy.

4. Research Hypothesis

4.1. Carbon Emission Trading Policies and Enterprises' Green Technology Innovation

Carbon emission trading policies belong to environmental regulation, and enterprises' green technology innovation belongs to the subdivision of enterprise innovation. In the existing literature, there are two mainstream views on the relationship between environmental regulation and innovation. One is the "cost-following" effect: environmental regulation increases the production cost of enterprises, which is not conducive to the growth of enterprises' economic profits [14]. The other is the "innovation compensation" effect: [15] emphasize that reasonable environmental regulations can promote enterprises' technological innovation and offset part of the environmental governance costs, which is conducive to enterprises' long-term development. Ref. [16] took the manufacturing sector of 17 European countries from 1997 to 2009 as a research object and confirmed that environmental regulations have a positive promoting effect on the output of innovation activities. Ref. [17] found that the EU Emission Trading System (EUETS) promoted regulated enterprises to innovate in low-carbon technology. A large number of empirical studies have shown confirmation of Porter's hypothesis, but there are also some empirical studies to the contrary. Ref. [18] studied German manufacturing enterprises and concluded that the greater the intensity of environmental regulations, the lower the patent applications of enterprises, which does not support Porter's hypothesis. Ref. [19] concluded through empirical tests that environmental regulations lead to inefficiencies in manufacturing technology in American states. The impact of environmental regulation on the technological innovation of enterprises is limited by many factors, such as regional economic development and external market uncertainty, and this field needs to be explored continuously.

Chinese scholars have carried out a series of studies on environmental regulation and enterprise innovation in combination with China's specific national conditions. At the same time, few scholars have studied whether the relationship between China's environmental regulations and enterprises' green technology innovation supports Porter's hypothesis at the level of micro-enterprises. Some scholars elaborated on the interaction law and quantitative relationship between the pilot emission trading policies and green innovation in a certain period of time based on the micro-enterprise level and drew the conclusion that emission trading policies promote enterprises' green innovation activities. The empirical results show that there is evidence to support Porter's hypothesis in some regions and industries in China. That is to say, environmental regulation policies have a positive impact on enterprises' green technology innovation. The results of previous studies provide a basis for this study on the impact of carbon emission trading policies, a specific type of environmental regulation, on enterprises' green technology innovation. The results of this study will provide a reference for the government to measure the policies' effects and enrich the research content of environmental regulations in regard to enterprise innovation in China.

Ref. [20] divided environmental regulations into two types: command-based and market-based and studied the impact of different types of environmental regulations on energy conservation and emission reduction technologies in prefecture-level cities in China. Ref. [21] discussed the impact of green production regulations on innovation from the perspective of firm heterogeneity. Empirical results showed that green production regulations have a negative impact on the R&D innovation of enterprises with a low R&D capacity or low R&D innovation enthusiasm. Some scholars divided the study's sample enterprises into state-owned enterprises and non-state-owned enterprises according to ownership. The empirical sample data showed that, as compared with the state-owned enterprises, the pilot policies had a more significant impact on the green technology innovation effect of non-state-owned enterprises. However, there are few domestic scholars who distinguish different environmental strategies when studying the effect of environmental regulations on enterprises' green technology innovation. Therefore, this paper, to some extent, fills this gap in the field by studying the problems of enterprises with different types of environmental strategies. The carbon emission rights trading policy is artificially set by the government,

which allocates the amount of greenhouse gas emissions in the production and operation of enterprises. Carbon emission rights have become a commodity, are endowed with value attributes, and can be bought and sold in the trading market. Reasonably designed environmental regulations can promote enterprises' green technology innovation [11]. In essence, carbon emission trading policies are part of the market's incentive environmental regulations. In order to protect the environment and save resources, the government directly controls and intervenes in enterprises' greenhouse gas emissions by establishing the carbon trading market. In this context, the carbon emission quota has become a scarce means of production and is incorporated into the planning of production and operation. Carbon emissions exceeding the quota must be purchased in the trading market, or the enterprise will face corresponding punishment and disposal. If the enterprise exceeds the allocated carbon emissions quota, it can be seen that the enterprise uses production resources less efficiently than other enterprises in the industry to some extent, and the enterprise will need to pay extra costs to buy the excess carbon emission permits. According to resource scarcity theory, in the case of the limited supply of carbon emission rights, the additional demand will increase the environmental governance costs of enterprises. In order to maximize profits, enterprises need to improve the utilization of resources or their pollution control capacity, which usually involves technological innovation to improve the production process. The technological innovation of enterprises under the constraint of carbon emission trading policies is inevitably related to the control of carbon emissions. According to the content of green technology innovation, it can be inferred that carbon emission trading policies have a positive impact on enterprises' green technology innovation. The promulgating of carbon emission trading policies and other environmental regulations reveal the trend of future policies and regulations and their impact on enterprises and encourages enterprises to make strategic deployments in advancing and accelerating the pace of green technology innovation to cope with the uncertainty of the external environment. The development of enterprises depends on natural environmental resources, and the rapid deterioration of the environment breaks the restoration of the ecosystem and the cycle of renewable energy, which is not conducive to the sustainable development of human society. The promulgation of such policies has also conveyed the urgency of environmental protection to enterprises, urging them to protect the environment to a certain extent; take the initiative in assuming social responsibility; carry out green technology innovation; and improve the recycling and disposal of waste, wastewater, and waste gas discharge in their production and operations. In conclusion, the H1 hypothesis proposed in this paper is as follows:

Hypothesis 1 (H1). *Carbon emission trading policies have a positive impact on enterprises' green technology innovation.*

4.2. Regulatory Effects of Environmental Strategies

According to Porter's hypothesis, the rational design of environmental regulations can promote technological innovation, and the strategies adopted by enterprises in response to environmental regulations are also the main factor affecting their level of green technology innovation. Under environmental regulations, enterprises generally use R&D and innovation investment to improve the energy consumption efficiency of manufacturing products and acquire technologies for the disposal and recycling of waste pollutants so as to offset the cost of environmental treatment. If an enterprise has a strong sense of environmental responsibility and implements forward-looking environmental strategies, it will take the initiative to control pollution and improve its technological process. Accordingly, R&D investment in green technology innovation activities will be higher than that of ordinary enterprises, and the R&D outcomes will be richer than those of other enterprises. Enterprises' green technology innovation achievements are generally transformed into a part of their production functions to improve the utilization rate of production factors and enhance their competitiveness [11]. The results of green technology innovation activities

will be disclosed to the public in annual reports and corporate social responsibility reports. Therefore, companies that disclose energy consumption and environmental performance in detail in their CSR reports or annual reports can be said to have a strong environmental awareness and are proactive in dealing with environmental regulations and other external uncertainties. When faced with carbon emission trading policies, such enterprises are more inclined to adopt forward-looking environmental strategies to improve resource utilization efficiency and control carbon emissions through R&D and innovation. As for enterprises implementing responsive strategies, environmental regulations are seen as laws and regulations that must be observed for the enterprises to meet their obligations. Such enterprises are not highly motivated to carry out green technology innovation activities, so their innovation results are relatively insignificant. However, the issuance of carbon emission trading policies increases, to some extent, the cost of environmental governance, has a negative impact on the enterprises' economic performance and hinders their long-term development. Under the constraints of the external environment and the impetus of their own development, enterprises tend to adopt green technology innovation to deal with the uncertainty of the future. Therefore, environmental regulation may also have a positive impact on enterprises' green technology innovation by causing them to implement reactive environmental strategies, but this incentive effect is lower than that of enterprises implementing forward-looking environmental strategies. In conclusion, Hypotheses H2a and H2b are proposed as follows:

Hypothesis 2 (H2a). *Carbon emission trading policies have a positive impact on the green technology innovation of enterprises implementing forward-looking environmental strategies and responsive environmental strategies.*

Hypothesis 2 (H2b). *Compared with enterprises that implement forward-looking environmental strategies, carbon emission trading policies have a greater positive impact on enterprises' green technology innovation.*

To summarize the above, the research contents of this paper include whether enterprises are constrained by carbon emission trading policies, environmental strategies, and green technology innovation. Drawing upon the research achievements of the existing literature, this article, in accordance with the policy, is limited to the pilot policy. It aims to determine whether the enterprises' policy constraints and green technology innovation, as disclosed in the green technology BVD patent database, are used to measure and study the influence of the policies related to green technology innovation in enterprises. Additionally, this paper also discusses enterprises' disclosure of social responsibility reports to identify corporate environmental strategies. The differences between green technology innovation under different environmental strategies are also discussed. The theoretical model of this study is shown in Figure 1.

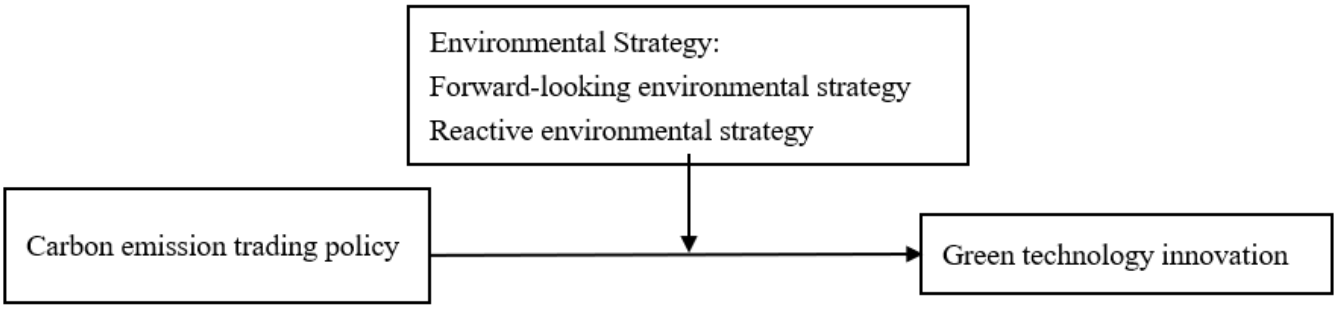

Figure 1. The theoretical model of this study.

5. Research Methodology

5.1. Research Methods

In order to effectively identify the impact of carbon emission trading policies on enterprises' green technology innovation, most of the literature adopts the method of difference-in-difference for quasi-natural experiments of the technology route. In this paper, referring to the research method of [22], the dummy variable was set according to whether the listed companies of Chinese enterprises are constrained by policies as the explanatory variable. The firm's green technology patent was taken as the explained variable. Additionally, DID was used to build the model; the time before and after the implementation of the policy was taken as the first difference; the second difference was carried out according to the pilot enterprises and non-pilot enterprises. This method can avoid the endogeneity problem and help determine the causal relationship. The specific econometric model is as follows:

$$\text{patent}_{it} = \alpha_i + \alpha_t + \beta_1 * \text{treated}_i + \beta_2 * \text{time}_t + \beta_3 \text{treated}_i * \text{time}_t + \lambda Z + \varepsilon_{it} \quad (1)$$

where i represents the sample enterprise; t is the year; Z represents the vector set of control variables; and ε is the error term. The core explanatory variable of this paper is as follows: if it is greater than zero, the policy effect is positive; if it is less than zero, it indicates that the policy has a restraining effect on enterprises' green technology innovation.

5.2. Variable Description and Descriptive Statistics

China's carbon emission trading policy was piloted in eight provinces and regions in 2013. This study took 2013 as the cut-off point and constructed the variable time. If the sample enterprise applied for a patent was after 2013, time = 1; if the sample enterprise applied for a patent was before 2013, the time was set as 0. The samples were divided into experimental and control groups according to whether the area where the sample enterprises were located belonged to the pilot area in order to study the impact of policies on enterprises' green technology innovation. The explained variable of the relevant structure indicated whether the enterprise was subject to policy constraints. If the enterprise belonged to the pilot area, the value of the relevant structure was 1; otherwise, it was = 0.

In this study, we followed [23] method of selecting measurement indexes when studying enterprises' green technology innovation. Considering whether the index can directly reflect the innovation level and the data availability of the enterprises, the number of patents was selected as the measurement index of the enterprises' green technology innovation among indicators such as R&D expenditure, patent number, and R&D innovation intensity. For enterprises, the carbon emission trading policy directly restricts their carbon emissions in the process of production, and this environmental regulation has a more intuitive impact on green process innovation. Therefore, enterprises' patent applications in this process were used as the main means of measuring enterprises' green technology innovation in this study. First, the technology classification of environmental protection technology patents was screened according to the WIPO. Second, according to the International Patent Classification (IPC), the categories of green technology innovation were subdivided, and the patents belonging to the following categories were extracted: B09 solid waste and contaminated soil treatment; C02 treatment of water, wastewater, sewage, or sludge; and E03 sewage treatment. The patent data of this study came from the Bureau Van Dijk (BVD) Global Intellectual Property Database. By searching for applications for green technology-related patents by Chinese listed companies from 2008 to 2020, 54,702 observed values of 1842 companies were obtained. The explanatory variable patent was constructed, which represents the number of green technology innovation-related patents of the sample enterprises in the calendar years from 2008 to 2020.

Most of the pilot enterprises are in high-carbon industries, such as the petrochemical, building material, steel, and electricity industries. Considering that the pilot enterprises covered by the policy are basically classified as industrial industries, in order to make the

estimation results more accurate, the samples of non-industrial enterprises were deleted, and the final observation values of the 1047 sample enterprises were 12,894, including 328 enterprises in the experimental group and 719 enterprises in the control group. Whether environmental regulation increases the cost of environmental governance or offsets the cost through technological innovation depends on many complex mechanisms. In the path of environmental regulation for green technology innovation, the heterogeneity among firms is a factor that cannot be ignored. In this study, enterprise-level control variables, including enterprise size, were selected. The number of employees of listed companies was collected through the GTA database, and the logarithmic scale was used to represent the scale. The maturity of the enterprise was assessed using the National Tai'an database to find the establishment time of the enterprise, and this was measured according to the age of the enterprise. In addition, the logarithm of total assets, solvency ratio, and profit rate of the listed companies were selected as control variables. Additionally, according to the information disclosed by the sample enterprises regarding environmental performance and resource consumption, different environmental strategies adopted by the sample enterprises in response to environmental regulations were divided in the GTA database. The description of variables and descriptive statistical results are shown in Table 1. We examined the released active disclosures of environmental performance, independent enterprises' implementation of strategies of corporate social responsibility, reports of proactive environmental strategies, non-disclosure to the public, and annual disclosure reports of environment strategies designated as reactive environmental strategies, and then studied different environmental strategies in different levels of enterprises' green technological innovation. The important role of a firm's subjective initiative, according to Porter's hypothesis, was then analyzed.

Table 1. Description of variables and descriptive statistical results.

Variable	Indicator	Mean	Sd	Min	Max
lnpatent	The logarithm of patents	3.789	1.875	0	11.143
lrl	The profit margin	8.006	14.861	−92.655	74.266
czl	Solvency ratio	53.403	18.756	−9.744	98.694
age	Enterprise maturity	21.602	5.344	5	62
scale	The enterprise scale	8.148	1.258	4.331	12.859
lncapital	The logarithm of the total assets of a business	20.982	1.392	17.402	26.539

5.3. Data Analysis Results

5.3.1. Parallel Trend Test

An important premise for the effective application of the DO method is that the control group and the experimental group should be homogeneous samples before the implementation of the policy; that is, there should be no systematic difference between the growth trends of green technology innovation patents in the two groups of the sample enterprises, and they should be as consistent as possible. Figure 2 shows the parallel trend test of the DO method. The horizontal axis represents the year, and the vertical axis represents the average number of patents applied by the sample enterprises. The study year can be divided into the non-pilot period (2007–2012) and the pilot period (2013–2020), taking the promulgating of the carbon emission trading policy in 2013 as the cut-off point. The dotted line represents the sample enterprises subject to carbon emission trading policies, which is the experimental group. The solid line represents the sample enterprises not subject to the policy, which is the control group. As shown in the figure, the number of patents in both the experimental group and the control group increased with time, and the number of patent applications in the experimental group was higher than that in the control group. The growth trend of the number of patent applications of the two groups of sample enterprises in the non-pilot period was roughly parallel; so, before the

implementation of the policy, the two groups of enterprises were homogeneous. Therefore, the parallel trend of the DO method can be confirmed graphically.

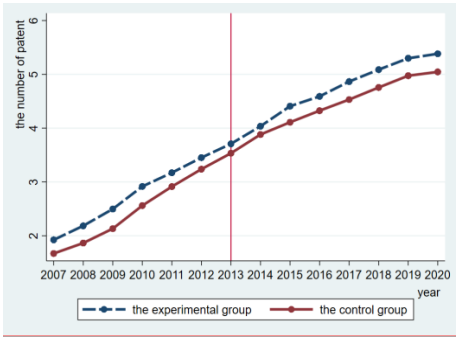

Figure 2. Parallel trend test.

5.3.2. Correlation Test

The impact of carbon emission trading policies on enterprises' green technology innovation was investigated without considering the control variables. The regression results are shown in Table 2. It was found that the coefficient of time * treated was significantly positive at the level of 0.1%, indicating that carbon emission trading policies promote enterprises' green technology innovation. Hypothesis H1 is thus confirmed.

Table 2. Regression analysis.

	(1)
	lnpatent
did	1.116 ***
	(27.36)
cons	3.570 ***
	(197.18)
N	12,609

t statistics in parentheses. *** $p < 0.001$.

On the basis of the above regression, the control variables were included to test the policy effect again, and the results are shown in Tables 3 and 4. It was found that the coefficient of time * treated was still significantly positive at the 1% level, which once again verifies the promoting effect of carbon emission trading policies on enterprises' green technology innovation. By comparing the results of the two regressions, the value obtained with the control variables was lower than that without the control variables, indicating that the impact of environmental regulation on enterprises' green technology innovation may be overestimated if other influencing factors affecting enterprise green technology innovation are not controlled.

Table 3. Regression analysis.

Source	**SS**	**Df**	**MS**	**Number of Obs**	**12,593**
				F(612,586)	451.5
Model	7839.49125	6	1306.58187	Prob > F	0
Residual	36,422.5574	12,586	2.8938946	R-squared	0.1771
				Adj R-squared	0.1767
Total	44,262.0486	12,592	3.51509281	Root MSE	1.7011

Table 4. Regression analysis.

Lnpatent	Coef.	Std. Err.	T	[95% Conf. Interval]	
did	1.099 ***	0.0383453	28.66	1.02367	1.173995
lrl	−0.007 ***	0.0011047	−5.91	−0.0086979	−0.0043672
lncapital	0.032	0.0215339	1.49	−0.0100346	0.0743847
czl	0.003 **	0.0010062	3.02	0.0010661	0.0050107
scale	0.500 ***	0.0217822	22.95	0.4570962	0.542489
age	−0.001	0.0028759	−0.26	−0.0063748	0.0048996
_cons	−1.267 ***	0.3533195	−3.59	−1.959487	−0.5743671

t statistics in parentheses. ** $p < 0.01$, *** $p < 0.001$.

This study examined whether enterprises take the social responsibility of independent detailed disclosures regarding environmental performance information, such as whether the enterprise can cope with environmental regulations of environmental strategies, defined as proactive environmental strategies and reactive environment strategies, and also investigated the impact of carbon emissions trading policies on different kinds of environmental strategies regarding green technological innovation. The influence of the results is shown in Table 5. It was found that the coefficients of time * treated in both the prospective and reactive groups were significantly positive at 1%, which was consistent with the conclusion of Hypothesis H1. Hypothesis H2a was also tested. By comparing the coefficients of the two groups of sample enterprises, it was found that the sample group with forward-looking strategies was higher than the sample group with reactive strategies. H2b can be assumed to be verified if the enterprises implementing forward-looking environmental strategy have a stronger promotion effect on the level of green technology innovation than those implementing reactive environmental strategy. Through comparison, it was found that the values of sample enterprises with a forward-looking strategy were greater than the results of the population sample regression, while the values of the population sample regression were greater than the value of the sample enterprises with reactive strategies. This result is consistent with the actual situation. On the basis of Hypothesis H1, carbon emission trading policies have a positive impact on the technological innovation of enterprises, so the regression result of the total sample must be significantly positive. For enterprises implementing forward-looking environmental strategies, under the dual role of the external promotion of policies and their own development needs, green technology innovation has achieved remarkable results. For enterprises implementing reflective environmental strategies, in order to achieve long-term development under the external constraints of policies, some enterprises carry out green technology innovation activities and effectively control carbon emissions. There are also some enterprises that pursue the hard target of policy formulation, and environmental regulations do not affect the enterprises' green technology innovation. The difference in the initiative between firms is the main reason for the difference between the regression results of the two groups of sample firms.

Table 5. Regression analysis.

Strategy	Forward	React
	lnpatent	lnpatent
did	1.196 ***	0.975 ***
	(16.73)	(20.17)
_cons	3.957 ***	3.377 ***
	(114.06)	(166.29)
N	4401	8208

t statistics in parentheses. *** $p < 0.001$.

5.3.3. Robustness Test

In order to verify the reliability of the estimation results, this paper discusses the stability test of the sample selection of the experimental group and the control group and

excludes the randomness of the empirical results caused by the selected sample enterprise data. According to the enterprises' disclosure of environmental performance in the sample enterprise group, the overall sample enterprises were divided into two categories: the proactive type and the reactive type, respectively, and from the two groups of enterprises, established the experimental group and the control group, including the pilot enterprises and other enterprises before and after the introduction of the policy of green technology innovation. The difference results are shown in Table 5. The coefficients of time * treated in the two sample groups were significantly positive at the 1% level, which was consistent with the baseline regression results and verified the reliability of the estimated results.

6. Conclusions and Discussion

6.1. Research Conclusions

Based on resource scarcity theory, the Porter hypothesis theory, and green technology innovation theory, we empirically analyzed the impact of carbon emission trading policies on green technology innovation of enterprises by establishing a panel data model and using the relevant data of 1047 listed enterprises in China. In this paper, the green technology innovation level of the enterprises was measured by the number of green patents, and the experimental group and the control group were divided according to the policy pilot area. Additionally, the enterprises carrying out different environmental strategies were distinguished, and the differences between the green technology innovation of the two types of enterprises under environmental regulations were compared. The main research results are as follows:

- First, carbon emission trading policies have a significant positive impact on enterprises' green technology innovation based on the consideration of the enterprise size, maturity, profit margins, and debt-paying ability ratio. The carbon emission trading policies restrain carbon emissions in the production and operation processes of enterprises, promote enterprises to carry out green technology innovation activities, and reduce the carbon emission per unit product. These policies have a significant effect on innovation promotion.
- Second, according to the information disclosure of environmental performance and energy consumption, different environmental strategies were divided into forward-looking strategies and reactive strategies. We classified the sample enterprises into different strategic types and found that environmental regulation has a significant positive impact on the green technology innovation of the two strategic types of enterprises and that the carbon emission trading policies have a greater promotion effect on the green technology innovation of enterprises with forward-looking strategies than those with reactive strategies.

6.2. Research Significance

6.2.1. Theoretical Significance

First, this study concerns the impact of environmental regulation on enterprises' innovation. Carbon emission trading policies are essentially a market-based tool in environmental regulation, and green technology innovation belongs to a subdivision of enterprise innovation. However, there are few studies on either of these topics. By starting from specific policies, this study enriches the relevant literature on the impact of environmental regulations on enterprises' green technology innovation and, to a certain extent, supplements the research on the impact of China's carbon emission trading policies on enterprises' green technology innovation.

Second, according to different environmental strategies, we divided enterprises into two categories: those that respond to the government's low-carbon policies and those that are obligated to adhere to low-carbon policies. In other words, this study explored the impact of policies within forward-looking and reactive environmental strategies on enterprises' green technology innovation, enriching the research perspective of such topics.

Third, regarding whether environmental policies can induce green technology innovation, the relevant research has shifted from the macro level to the micro level, that is, from a focus on industry and regional green technology innovation to a focus on enterprises' green technology innovation. At present, there are few studies on the enterprise level; thus, this paper enriches the research content at the micro level and tests whether the Porter effect can be achieved in the context of carbon emission trading in China from the perspective of enterprises so as to provide evidence for the applicability of the Porter hypothesis in developing countries.

6.2.2. Practical Significance

First, for the government, China's carbon emissions trading policy, beginning from a single pilot and being expanded to many parts of the city and across the country, is in a stage of exploration and testing; thus, this research on the impact of carbon emissions trading policies regarding the influence of green technology innovation within the context of past and present government-issued policies can help scientifically evaluate and provide evidence of the enterprises' levels of development. At the same time, this study provides some reference for the government regulatory departments.

The empirical results show that the issuance of carbon emission trading policies has a significant positive impact on the green technology innovation of enterprises. This conclusion indicates that the carbon emission trading policies not only rigidly constrain the carbon emissions of enterprises but also have a positive impact on the internal innovation activities of enterprises and promote the growth of enterprises' soft power. The government can accelerate the steady progress of carbon emission trading policies across the whole country step by step to control the carbon emissions of enterprises while guiding and stimulating the innovation of green technology. In addition, the relevant systems of the carbon trading market should be improved to ensure that enterprises can operate conveniently in the process of carbon trading and try to eliminate the obstacles that affect the maximum effect of policies on innovation promotion.

Second, for enterprises, the promotion of carbon emission trading policies across the country is the current trend within the external legal environment. Different environmental strategies adopted by enterprises will have different results in their green technology innovation. The policy of carbon emission constraint is an inevitable external pressure for the future development of enterprises. This study provides a reference to help enterprises make strategic planning and deployment in the face of the macro-environment and realize sustainable development. The proactive implementation of forward-looking environmental strategies, the active undertaking of environment-related social responsibility, increasing investment in green technology innovation, and the accumulation of green knowledge and technical capacity can help enterprises to achieve sustainable development in the context of environmental regulations. Under carbon emission trading policies, the carbon emissions of enterprises in the processes of production and operation are constrained. Enterprises generally reduce the carbon emissions of unit products by controlling the total output or using technological innovation. Under the constraint of policy, controlling the total production is not conducive to the long-term development of enterprises, and it is an effective way for enterprises to achieve sustainable development by responding to external environmental regulations through green technology innovation. A policy can also constrain enterprises, so the enterprise can convey certain signals, such as the industry standards for carbon emissions. Enterprises should, according to the use of carbon emissions quotas and purchase quotas, adjust their own green technology innovation activities to achieve carbon emission levels above those of the industry standard, thereby ensuring enterprises remain active under policy constraints and avoiding external uncertainties that put enterprises in a passive position.

6.3. Research Limitations and Prospects

First, the implementation time of the carbon emission trading policies in the pilot areas was different. In consideration of the convenience of panel data processing, the cut-off point of this paper was uniformly divided according to 2013. Future research on this issue can conduct the doI test according to the region, which can pinpoint the cut-off point of policy implementation in each region so as to obtain more accurate results. At the same time, the influence of regional economic development differences in the regression results can be excluded.

Second, this study used the carbon emission trading policies of the pilot provinces or cities for fuzzy matching of pilot enterprises and non-pilot enterprises. In fact, since the policy is in the pilot stage, the carbon emission trading policy has a binding effect on some key enterprises in the pilot area. When studying this problem in the future, we can accurately match the list of pilot enterprises and study the differences between green technology innovation levels of pilot and non-pilot enterprises.

Third, we used the number of green technology patents to measure the innovation level of enterprises, but the number of patents cannot fully represent their innovation level. Companies may acquire patents through means other than their own research and innovation. Future research can include the amount of R&D investment and the proportion of the number of green patents in the total number of patents within the measurement of green technology innovation of enterprises so as to estimate the policy effect more accurately.

Author Contributions: Conceptualization, Funding acquisition H.T.; Formal analysis, Data curation, Writing-original draft J.L. Corresponding, Writing—review & editing revision C.J.; All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Post-Funded Projects of the National Social Science Foundation of China, grant number [20FGLB039].

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data used to support the findings of this study are included within the article.

Conflicts of Interest: The authors declare no conflict of interest.

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