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How Does a Green Supply Chain Improve Corporate Carbon Performance

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Abstract: Drawing from A-share listed companies' data from the Shanghai and Shenzhen stock markets in China (2013–2022), this paper adopts the differential model to test the impact and mechanism of a green supply chain (GSC) pilot on pilot enterprises. The results show that the GSC pilot effectively improved the carbon performance of the pilot enterprises and passed a series of robustness tests. Mechanism analysis finds that green innovation, efficiency improvement, and environmental information disclosure (EID) can reduce the carbon emissions of enterprises. The moderating effect discovers that environmental regulation and environmental attention effectively strengthened the role of the GSC pilot in improving carbon performance. In addition, this paper finds that the pilot had a better carbon reduction effect on mature, technology-intensive, and non-state-owned enterprises. The above research conclusions provide strong support for the government to build a GSC and promote low-carbon development.

Keywords: green supply chain (GSC); corporate carbon performance; green innovation; efficiency improvement; environmental information disclosure (EID); environmental regulation (ER)

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1. Introduction

Confronting global climate pressures, the "dual carbon" goal marks a new era of low-carbon, green development. Yet, despite widespread carbon reduction measures, their effectiveness lags behind expectations. At the macro level, policy implementation is influenced by policy design, regulatory capacity, and policy-market coordination. These factors hinder policy effectiveness. Sectorally, industries face varying challenges in reducing emissions, especially high-energy-consuming sectors. Technology, capital, and market barriers make effective emission reductions difficult. Additionally, the industrial chain lacks a cohesive emission reduction mechanism, limiting overall effectiveness. Upstream enterprises' emission reductions can be offset by downstream demand changes, undermining overall reduction effectiveness. At the microenterprise level, some prioritize profits over carbon reduction, lacking willingness and ability. Others face technical, capital, and management challenges. To enhance outcomes, macro policy support and microenterprise initiatives are essential. Establishing a sustainable global supply chain is crucial but remains challenging.

This paper aims to investigate the significance of GSC initiatives as a crucial pathway for enhancing corporate carbon performance. In other words, does the GSC pilot exert a notable influence on corporate carbon performance? If so, is this impact positive or negative? More importantly, through what mechanism and regulating effect do GSC pilots affect corporate carbon performance? What are the differences in terms of heterogeneity? The issues discussed in the following sections have important theoretical and practical implications for us to rigorously examine and identify causal relationships.

Literature Review

1. Factors Influencing Corporate Carbon Performance

Researchers debate factors influencing corporate carbon performance, exploring macro- and micro-level contexts. Macro studies focus on the policy and social environment, with policy factors being crucial. Some studies focus on innovative city pilot policies [1], smart city construction pilot policies [2], green credit policies [3], technology and finance policies, and low-carbon pilot policies [4], which are all favorable factors to improving corporate carbon performance. Yet, concurrently, some scholars contend that the export tax rebate policy [5] will hinder the improvement of corporate carbon performance. In terms of social environment, some literature focuses on the growth and expansion of digital finance in Chinese cities [6], population aging [7], population mobility under the background of the digital economy [8], and the market background of economic transformation [9], which significantly improves the carbon emission performance. Some scholars analyzed that fiscal competition among local governments [10] led to relaxed environmental management, resulting in looser corporate carbon emission policies and reduced performance. Micro-level research focuses on enterprise technology upgrading and internal management, with direct technological innovation playing a significant role in carbon emission performance. Green technology innovation [11] drives green and intelligent development, transforms high-input models, and industrial intelligence [12] improves carbon performance through structural upgrades and factor allocation. The digital economy [13] and digital finance [14] enhance industrial agglomeration and green innovation, boosting carbon performance. In management, active human capital investment [15] and international talent [16] promote process and product upgrades. In enterprises actively reducing carbon emissions [17], stronger corporate environmental responsibility leads to higher emphasis on carbon emissions, improving performance. Existing research mainly focuses on macro-level factors like national policy and enterprise technology, with limited micro-level supply chain analysis. Hence, this paper explores the link between GSCM and carbon emission performance from a GSC perspective.

2. Green Supply Chain Management and Green Supply Chain Performance

Currently, domestic GSC literature focuses on management strategies and performance. GSCM, a new mode to cut costs and pollution, emphasizes meticulous management, internal collaboration, and external stakeholder connections. However, enterprise GSCM faces issues like low GSC adoption, ineffective supplier evaluation, high green R&D investment, low recycling efficiency, and high green product prices [18]. The establishment of a GSC is crucial in management. GSCM focuses on green materials, green supplier management, and green distribution. In raw material selection, eco-friendly options are prioritized, material variety is minimized, substitutes are used to reduce waste and consumption, and packaging should be recycled to minimize waste [19]. Supplier selection is vital in GSCM. To ensure smooth implementation, enterprises should pursue zero emissions and green management; consider the supplier's industry, prospects, reputation, and ability; and establish an evaluation system based on quality, service, environmental performance, and financial status to choose the best supplier [20]. Regarding distribution, suppliers should ensure synchronous production and control the distribution radius, choosing low-carbon transportation to minimize environmental impact [21]. GSCM's main goal is to enhance supply chain performance. Industries use different rating systems. Some scholars assess green petrochemical supply chains via hierarchical variable weight methods, while others create evaluation frameworks based on SCOR models and balanced scorecards in the GSC industry. Input-DEA's C2R and BC2 models are used for new industry performance evaluations [22]. Some scholars use the AHP-entropy method for weighting indicators and the fuzzy matter-element model with Euclidean closeness to assess GSC performance in manufacturing [23].

Furthermore, GSCM research has broadened to encompass specific models and strategies. Scholars have employed a two-stage stochastic programming model for deteriorated products, creating a green, centralized supply chain to cut costs and emissions. They explore circular economy solutions for second-hand products and reassess supply chain business models. Addressing uncertain demand, the model optimizes orders, transportation, and contracts, balancing economic and environmental goals and offering insights on reconciling incentives and responsibilities in circular supply chains [24]. Other studies have also found that carbon trading policies, based on the fixed demand SV-SB inventory model, are more economical despite their complexity, as they incorporate carbon taxes and emissions trading policy costs to balance costs and emissions [25]. These studies provide guidance for GSCM practice.

2. Policy Background and Research Hypotheses

2.1. Policy Background

To improve the level of supply chain modernization, enterprises need to achieve low emissions in the supply chain link and achieve GSC in the whole area. Before 2018, there were only four GSC pilot cities in China. The GSC covered a small area and involved only a few industries. Therefore, in April 2018, the Ministry of Commerce and other departments of the People's Republic of China issued the Notice on Carrying out the Pilot Project of Supply Chain Innovation and Application and decided to carry out the pilot project in cities and enterprises nationwide, so as to further improve the supply chain system and enhance the competitiveness of China's industrial chain and supply chain. The circular encourages pilot cities to vigorously develop a whole-process and whole-link GSC system, give priority to the procurement of green products, and improve the EID system. Pilot enterprises are encouraged to innovate supply chain technologies and models with the help of digital technology, build and optimize industrial collaboration platforms, and improve industrial integration and collaboration so as to promote enterprises' cost reduction and efficiency, green development, and industrial transformation and upgrading. It can be seen that the circular is an important quasi-natural experiment for GSC practice in pilot cities and an important practice for enterprises to promote green supply chain management.

2.2. Theoretical Framework

2.2.1. Green Technology Innovation Hypothesis

The "Porter Hypothesis" states that while ER increases production costs for enterprises in terms of environmental protection, it also motivates them to engage in green technological innovation. For some enterprises, due to the failure of the resource market, cost constraints, and other factors, the internal motivation for carrying out GTI is not high, and they need to rely on the promotion of external regulation forces. When the government implements environmental regulatory policies, it will internalize the negative externalities on the environment caused by the production behaviors of enterprises, bringing about an increase in the production costs of enterprises and forcing them to change their production decision-making behaviors in order to re-attain the goal of profit maximization [26]. On the one hand, as the government implements economic policies for ER, including emission charging, emission rights trading and subsidy, tax, carbon emission control, etc., enterprises will take corresponding measures to reduce pollutant emissions, such as purchasing pollutant discharge equipment, using more advanced pollutant discharge technology, using clean energy, etc., to make the production and operation process green, and these measures will elevate the production expenses incurred by enterprises. On the other hand, from the perspective of the long-term development of enterprises, green technology innovation can bring long-term competitive advantages to enterprises. The increase in production costs and the pressure of market competition will enhance the driving force for green innovation in enterprises and push them to restructure and optimize resources and innovate production technology. Through such green innovation actions, enterprises can relieve the pressure of short-term costs resulting from government ER policies, thereby accomplishing a dual victory in both environmental protection and economic growth.

2.2.2. Supply Chain Synergy Theory

The supply chain network is centered around the core enterprise, connecting suppliers, manufacturers, distributors, retailers, and end-users by managing the streams of information, logistics, and finances, forming a functional network with input-output relationships. Supply chain synergy means that each node (enterprise) of the supply chain network exerts influence on the upstream and downstream by using network externalities and exerts effect on the supply chain structure elements (relationship between enterprises) so as to realize the faster and better collaborative response of enterprises on the supply chain network to customer demand. The single-chain structure of traditional supply chains has the limitations of a low degree of information sharing, slow market response speed, and high operational risk, which restricts the efficient operation of supply chains. In the GSC, under the supply chain network, enterprises jointly promote the greening of supply chains and carry out emission reduction cooperation at the supply chain level, which can play a synergistic role among enterprises and achieve the synergy of 1 + 1 > 2. For example, it is difficult for a single enterprise to achieve zero-carbon planning through production technology innovation, procurement of green and zero-carbon raw materials, recycling and utilization of renewable resources, etc., while upstream and downstream enterprises cooperate with each other to give full play to their respective strengths and achieve scale effect through resource integration, which can greatly improve efficiency and reduce costs [27]. In addition, supply chain synergy has a knowledge spillover effect, and upstream and downstream enterprises can absorb and transform green technology spillover from the supply chain network, thus enhancing the green level of the entire supply chain network [28].

2.2.3. Sustainable Development and Stakeholder Theory

Sustainable development is adapting to contemporary development needs without compromising long-term development benefits. Stakeholder theory represents a progression from the principles of sustainable development. According to stakeholder theory, integrating stakeholders into decision-making is not only an ethical requirement but also a strategic resource, both of which help enhance enterprises' competitive advantage to achieve sustainable development in the long run. To be specific, enterprises should not only focus on their own economic profits but also shoulder social responsibilities to safeguard the overall interests of stakeholders and meet the ethical requirements of society. Enterprises need to consider the interests of and be subject to the constraints of stakeholders, including governments, the public, consumers, the natural environment, and so on. In the current accounting information disclosure system, environmental responsibility belongs to voluntary disclosure information. Therefore, enterprises proactively disclose their internal environmental management, pollution monitoring data, and other environmental information that affects the interests of stakeholders, which is the embodiment of the pursuit of sustainable development by considering ecological and social interests.

2.3. Mechanism Analysis and Research Hypothesis

2.3.1. Green Innovation Mechanism

The realization of green innovation by enterprises through technological progress is one of the key ways to improve carbon performance. The Porter hypothesis states that when the government implements stringent ER, the internalization of pollution costs occurs, endangering business profits. Nie et al. [29] and Tseng et al. [30] made clear that enterprises will focus more on the balance between carbon dioxide emission costs and operating profits. In this case, enterprises bearing higher carbon emission costs tend to take the initiative to reduce the profit loss through production technology reform and process innovation. The circular requires enterprises to actively cooperate with universities and research institutions, carry out supply chain technology innovation and software and hardware research and development, promote the use of cutting-edge green technologies and models of the supply chain, and improve the digitalization and intelligence of the entire industrial supply chain.

Increased investment in low-carbon and digital technologies, along with the development of professional expertise, will help enterprises decrease environmental costs and improve resource use [31].

The importance of the GSC pilot policy in advancing enterprise green innovation becomes evident through the circular issued by relevant commercial departments in 2018, regarding the application of the Supply Chain Innovation and Application pilot program. The circular requires the pilot enterprises to strengthen the alignment and consolidation of the supply chain enterprises to attain a decrease in industrial costs and an increase in efficiency and green development. By collaborating strategically with partners, businesses can procure eco-friendly resources, manufacture eco-friendly goods, improve green innovation capabilities, and optimize production processes [32]. In addition, policies encourage enterprises to benchmark international leading supply chain practices and boldly explore technological innovation and other aspects. Enterprises in GSC actively integrate environmental protection ideas into supply chain management, promote technological innovation activities, and find a Roman avenue leading to both environmental protection and economy [33]. Secondly, the pilot policy also alleviates the financial pressure on enterprises in technology research and talent introduction through government subsidies and green financial credit. In the long run, enterprise, through continuous green innovation, helps to keep an advantage in market competition. In addition, from the policy level, it can be seen that the traditional supply chain can no longer adapt to the national "dual carbon" goal, and we must seek a new path of green development through technological progress.

Therefore, the first research hypothesis is proposed:

H1. *GSC pilot can improve corporate carbon performance through a green innovation mechanism.*

2.3.2. Efficiency Improvement Mechanism

According to the supply chain synergy hypothesis, GSC can minimize carbon dioxide emissions by increasing supply chain efficiency. Efficiency refers to improving the efficiency of information movement, logistics, and monetary flow. Under the GSC network, the goods from material acquisition, processing, packaging, warehousing, shipping, and usage into the entire scrap recycling process, each node firm to perform the smallest environmental effect and the highest resource efficiency. When corporations require reduced cooperation, emphasize the importance of enterprise cooperation. Through cooperative behavior, subparts of the supply chain can be greater than the part and whole; 1 + 1 > 2 brings the value-added effect to full play.

Second, the circular states that pilot companies should use modern information technology to develop novel models and technologies, build and optimize industrial collaboration platforms, and create a green and efficient supply chain system. According to product life cycle theory, products should consider their environmental impact from the time they enter the market until the time they exit. Throughout the supply chain, each node of green logistics uses multimodal transport, low-carbon transport, alternative logistics, and warehousing management strategies to reduce logistics costs and lower carbon emissions. For example, replacing ship transportation between China and Europe with long-distance rail transportation will avoid potential marine pollution in favor of relatively more manageable land-based pollution.

Furthermore, by encouraging collaboration between the supply chain's core enterprises and financial institutions, the supply chain financial service mode is being developed to ensure the efficient entry of funds into the real economy, realize optimal resource allocation, and improve the efficiency of capital flow service. This can inspire them to produce clean energy and invest more in research and innovation to support enterprise transformation and upgrading.

Therefore, the second research hypothesis is proposed:

H2. *GSC pilot can improve corporate carbon performance through an efficiency improvement mechanism.*

2.3.3. Environmental Information Disclosure Mechanism

Conjectured from sustainability and stakeholder theory, the GSC will also reduce carbon emissions by influencing companies' EID. Corporate EID refers to the revelation of corporate internal environmental management, emission monitoring reports, environmental behavior, and additional environmental data that could present market risks and influence investors' or the public's interests. Through disclosure, stakeholders such as the government, financial institutions, and the public can understand the efforts of the company, indicating that the company has taken into account social responsibility while pursuing profit and has contributed to sustainable economic and environmental development.

In recent years, related departments have issued environmental information disclosure guidance to gradually improve the regulations on the EID of Chinese enterprises. The daily production and operation activities of enterprises are the main components of greenhouse gas emissions. With the aggravation of global environmental problems and the increasing pressure of carbon neutrality, enterprises' EID has become increasingly important [34].

The success of the present will benefit the future. The purpose of EID is to improve the enterprise's environmental protection consciousness, prompting them to weaken emissions of greenhouse gases in production and business operations. Based on the stakeholder theory, investors need to assume the risks when making specific investments in the enterprise. As the Chinese government continues to practice the concept of sustainable development, investors are gradually aware of the risk of economic losses that EID may bring [35]. To cater to the preferences of investors and seek their survival and development, and grasp the potential investment opportunities, enterprises should actively convey the concept of environmental protection and show practical results to investors. Therefore, based on the expectations of investors, enterprises will take corresponding emission reduction measures to carry out clean production so that the disclosure content can achieve the purpose of environmental protection [31,36].

On the other hand, the government requires listed companies to follow the rules and regulations on information disclosure or face severe penalties. In addition, the EID can promote public participation and strengthen social supervision. Ren et al. [37] pointed out that after the public obtains corporate environmental-related information through third-party environmental organizations, it can exert environmental pressure on enterprises, which further promotes them to adjust energy structure, improve production efficiency, and reduce carbon emission intensity. In conclusion, investors, government, consumers, and other stakeholders need to encourage enterprises to disclose environmental information and take responsibility for energy conservation and emission reduction.

The following third research hypothesis is suggested in light of the analysis above:

H3. *The GSC pilot can enhance businesses' carbon performance via the EID mechanism.*

2.3.4. Moderating Effect of Environmental Regulation

ER is a form of institutional constraint imposed by the government on enterprises [38], which refers to the restrictive means of intervention and management of resource utilization by national or local governments through laws and regulations, administrative management, and economic means in order to maintain ecological balance. In the field of enterprise carbon performance, ER means intervening in the production mode of enterprises, guide and supervise them to complete the construction of GSC. On the one hand, according to the theory of cost, ER will make enterprises internalize the impact on the environment, and the improvement of ER intensity will increase the cost of environmental governance. On the other hand, according to the first-mover advantage theory, enterprises subject to ER will pay more attention to green innovation activities to gain certain competitive advantages in the supply chain [39]. Furthermore, from the perspective of the difference in ER intensity, the stronger ER is, the greater the promotion effect on green technology innovation [40].

Therefore, the fourth research hypothesis is proposed:

H4. *ER may have a positive moderating effect on the GSC pilot in enhancing corporate carbon performance.*

Mechanism analysis based on the above theory, to set up in this paper, theoretical research framework, can be seen in Figure 1.

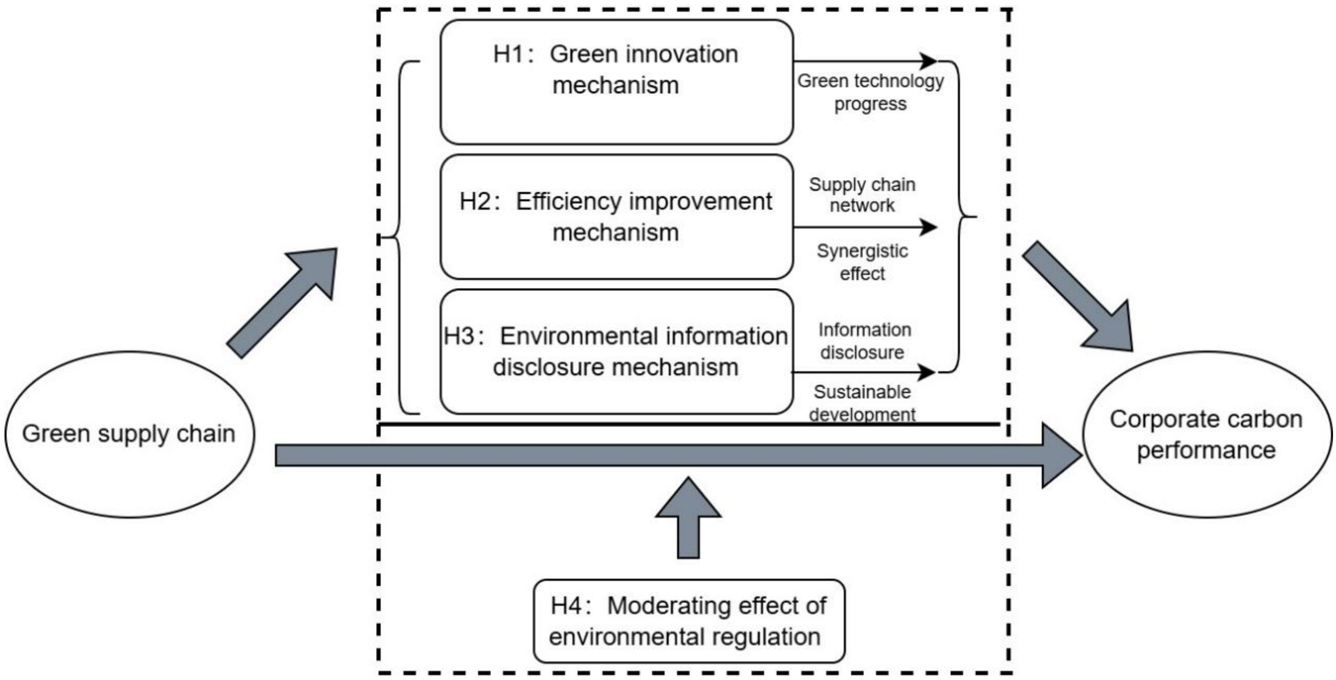

Figure 1. Theoretical research framework.

3. Research Design

3.1. Basis of Empirical Analysis: Samples and Data

We chose the carbon emission data, green patent application data, financial data, and EID data of A-share listed companies in Shanghai and Shenzhen stock markets from 2013 to 2022. Carbon emission data of listed companies, financial information, and green patent data was primarily from the Taian database (CSMAR), in part due to the lack of the statistical indicators used the Chinese research data services platform (CNRDS) to supplement relevant data. Some enterprises have missing data for some years, and this paper uses the technique of average growth rate to fill in the blanks in the data. In this paper, the initial samples for the screening process in the paper are as follows: (1) excluding ST, * ST, and PT companies samples with AB cross samples of listed companies; (2) considering the different financial structures, excluding financial samples of listed companies; (3) considering the influence of the political cycle, eliminate the samples of listed company of 2013 years ago; (4) to remove the impact of the outliers in this research, and the end processing of the continuous control variables involves subjecting them to a 1% level of shrinkage. (5) Eliminate the samples with missing key variables. This paper finally obtains a total of 21,242 observed values from 2013 to 2022.

3.2. Measurement Model Design

Enterprises are the major players that affect carbon emissions due to their daily production and operation. Deloitte's survey on the decarbonization readiness of Chinese enterprises in 2021 showed that enterprises will achieve the goal of peaking carbon emissions by 2030 ahead of schedule. We are concerned about the change in enterprises' carbon dioxide emission efficiency after the government issued the Notice in 2018. Therefore, referring to the practice of Du et al. [41], the DID model is used to identify the effect of the GSC pilot policy on the carbon performance of the pilot enterprises.

The dummy variables in this paper are from the pilot enterprises announced in the Notice. The experimental group, which comprises the pilot enterprise, is contrasted with the control group, consisting of the non-pilot enterprise, to precisely ascertain the net impact of GSC construction to enhance the carbon performance of enterprises. Here is how the particular model is configured:

$$carbon\_emi_{it} = \beta_0 + \beta_1 Time_t \times Firm_i + \beta_2 X_{it} + \mu_t + \varphi_i + \varepsilon_{it} \quad (1)$$

This model studies the impact of GSC on corporate carbon performance. $Time_t$ as its time dummy variable, the value of enterprise samples from 2013 to 2017 is 0, and the value of enterprise samples from 2018 to 2021 is 1. $Firm_i$ is the enterprise virtual variable, the value of GSC pilot enterprises is 1, and the value of non-pilot enterprises is 0. Carbon_emi is the enterprise's carbon performance measured by the ratio of business revenue to the logarithm of carbon emissions. X_{it} is the control variable at the enterprise level. The last three terms of Equation (1) are year fixed effect (μ_t), firm fixed effect (φ_i), and the random disturbance term (ε_{it}). Year-firm fixed effects absorb $\mathrm{Time_t}$ and $\mathrm{Firm_i}$ in the specific regression process, respectively. This paper mainly observes the coefficient of differential term β_1, which measures the direct influence that the GSC has on the carbon performance of enterprises. If β_1 is significantly positive, it suggests that the carbon performance of businesses is significantly improved by the GSC.

3.3. Definition of Variables

Explained variable: The existing literature on carbon emissions calculation basically concentrates on the measurement of carbon dioxide emissions at the absolute quantity level [4,42], and there are also relative indicators starting from the aspects of carbon emission intensity and carbon emission efficiency [43,44]. To consider enterprise size's impact on carbon emissions, the dependent variable in this paper, namely carbon emission performance, is the ratio of the logarithm of a firm's operating revenue to its carbon emissions.

Core explanatory variable: The dummy variable of GSC construction pilot policy.

Mechanism variable: The green innovation indicator: Since there are no green patents involved in design patents, the quantity of green patent applications is a surrogate measure of technological innovation in corporations based on the practice of [34,45]. Green invention patents and green utility model patents are included in the total number of applications for green patents. This article chooses green patent application number and license number was chosen not because patent application number on the aging more directly reflects the enterprise innovation performance, unlike authorized patents, which need to experience a longer review process to influence the model of green innovation effort degree of consideration [45]. Supply chain efficiency index: On the basis of the enterprise inventory, supply chain efficiency is further reflected by inventory turnover days, which is calculated as ln(365/inventory turnover). EID index: Referring to the index scoring method of Cho and Patten [46], this paper scored the corresponding index based on what is disclosed in listed companies' EIDs. The scoring range is 0-2 points, and the score is assigned according to the degree of disclosure. Add enterprise each index score for the sum of the EID, total score as the proxy variable regression of EID.

Moderating variable: Based on the idea of Fredriksson and Millimet [47], considering the differences in the scale and business level of different enterprises, the ratio of enterprise pollutant discharge fee to business income is selected as the measurement index of environmental regulation (Enre), and its ratio directly reflects the intensity of enterprises under environmental constraints. Environmental attention (EA) adopts the ratio of environment-related word frequency to total word frequency in provincial government work reports.

Control variables: in order to eliminate interference, a series of control variables selected in this paper are shown in Table 1:

Table 1. Control variables.

Variables	Method of Measurement
The scale of enterprise:	Natural logarithm of the firm's total assets at the end of the period
Enterprise age:	Logarithm of the establishment time of the firm
Asset–liability ratio:	The ratio of total liabilities to total assets of a firm
The enterprise market power	The ratio of a firm's sales to its operating costs
The independent directors proportion	The proportion of the number of independent directors to the total number of directors on the board
Capital expenditures	The ratio of annual capital expenditure to total assets of an enterprise
ROA (return on assets)	The ratio of net profit after tax to total assets of the enterprise
Ownership concentration of enterprises	The shareholding ratio of the top ten shareholders measures the ownership concentration of enterprises
Separation degree of two rights	The degree of separation of equity and management rights in the corporate governance structure
Nature of equity	The dummy variable of the nature of enterprise equity is set, and the value is 1 for state-owned enterprises, and 0 for otherwise

The descriptive statistics of control variables are as follow in Table 2:

Table 2. Descriptive statistics.

Variables	Sample Size	Average	Standard Deviation	Minimum	Maximum
Carbon_emi	21,242	1.885	0.139	1.195	6.724
Asset–liability ratio	21,242	0.41	0.2	0.058	0.874
Degree of separation of Two rights	21,242	4.998	7.478	0	28.068
Ownership Concentration	21,242	60.471	14.786	25.688	91.168
Roa	21,242	0.44	0.057	−0.187	0.209
Enterprise size	21,242	22.249	1.335	19.999	26.41
Whether state Ownership	21,242	0.329	0.47	0	1
Age of business	21,242	2.868	0.326	1.946	3.497
Corporate market Power	21,242	1.545	0.889	0.558	6.711
Proportion of Independent directors	21,242	0.377	0.053	0.333	0.571
Capital expenditure	21,242	0.05	0.045	0	0.217

4. The Empirical Results and Analysis

4.1. DID Regression Results

It can be observed from the data in column 1 of Table 3 that by controlling for industry and year-fixed effects, the regression analysis between carbon performance and the DID yields a negative and statistically significant coefficient at the 1% level. Conversely, column 2 shows that the fixed effect of the control firm and the fixed effect of the year, without adding the control variable, the coefficient is negative and not significant. Additionally, the data presented in Column 3 indicates that when both industry-specific and annual fixed effects are managed, along with the introduction of control variables, the DID estimator turns positive with a significance reaching 1%. Moving to Column 4, the results suggest that by controlling for individual firm fixed effects and year fixed effects and adding firm control variables, the coefficient of the difference of differences term is positive at the 5% level of significance. In all benchmark regressions, it is crucial to consider year-fixed effects so that they are fully absorbed. The results in the last two columns show that GSC significantly improves corporate carbon performance after including a series of control variables.

Table 3. Benchmark regression.

	(1)	(2)	(3)	(4)
Time × Firm	−0.1341 ***	−0.0015	0.0165 ***	0.0022 **
	−0.001	−0.001	−0.005	−0.001
Control			YES	YES
_cons	1.8856 ***	1.8847 ***	3.3652 ***	2.8495 ***
	0	0	−0.043	−0.021
N	21,242	20,995	21,242	20,995
r2	0.0413	0.644	0.5062	0.6789
Industry	YES		YES	
Year	YES	YES	YES	YES
Enterprise		YES		YES

Note: In parentheses are the robust standard errors clustered to the industry level, ** $p < 0.05$, *** $p < 0.01$.

4.2. Robustness Test

4.2.1. Parallel Trend Test

To satisfy the parallel assumption trend, the double difference model is the necessary premise; that is, before the GSC pilot policy is formally implemented, there is no systematic difference in the time trend of carbon performance between the experimental group and the control group. With particular reference to Amore et al.'s [48] research methods, the event analysis method is adopted to incorporate the interaction terms of the dummy variables in the first 4 years and the last 2 years of the enterprises affected by the pilot policy on the baseline model, specific form as shown in model (2):

$$Carbon\_emi_{it} = \beta_0 + \sum_{n=1}^{4} \gamma_n Pre_{it}^n + \beta_1 current_{it} + \sum_{n=1}^{2} \delta_n Las_{it}^n + \sum \theta_i Control_{it} \quad (2)$$

where Pre^n is a dummy variable, the sample company became a pilot company n years ago, and the value is 1. The fourth period prior to the application of the policy is removed from the regression to prevent collinearity interference; Current for the virtual variables, sample enterprises become the pilot enterprises in the Current year assignment for 1; Las^n is the virtual variables, sample enterprises in n years later to become a pilot enterprise assignment as 1. If the estimated coefficient of the core explanatory variable is significantly positive before the implementation of the pilot policy, it indicates that the original estimation result is biased, and it is guessed that it is affected by some factors that are difficult to observe. Otherwise, it can be proved that the improvement of the carbon performance level of the sample enterprises is brought by the implementation of the GSC pilot policy.

Table 4 lists the parallel trend results after the test. The coefficient estimates of the dummy variables in the first three years of the policy implementation year 2018 are not significant, and the research samples meet the assumption of a parallel trend. From 2018 to 2020, after the pilot policy implementation of GSC, the 1% level was significantly positive, showing that the policy effect estimated in this paper is robust.

However, the DID theoretical study by Roth et al. [49] pointed out that the traditional pre-treatment trend test has limited statistical power in validating the parallel trend hypothesis and may introduce estimation bias. This finding challenges existing research practice. In response to this, Rambachan and Roth [50] propose a robust test when the hypothesis of parallel trends is in doubt. This method uses deep confidence interval inference and sensitivity analysis to process point estimators of effects and evaluate their robustness under different deviating parallel trend assumptions. The method consists of two steps: one is to quantify the maximum possible deviation (Mbar) of the parallel trend hypothesis; Second, based on this deviation, the confidence interval of the estimated points after processing is constructed. If the 0 value is still excluded in the confidence interval under the most unfavorable scenario, it indicates that the treatment effect is highly robust to parallel trend deviation, which enhances the credibility of the research conclusion.

Table 4. Parallel trend test.

Variables	Carbon_emi
pre_3	0.0183
	−0.006
pre_2	0.0082
	−0.006
pre_1	0.0047
	−0.006
current	0.0145 ***
	−0.005
las_1	0.0262 ***
	−0.006
las_2	0.0285 ***
	−0.005
Control	YES
Sicmen/YearFE	YES
N	21,242
R-squared	0.5062

Note: In parentheses are the robust standard errors clustered to the industry level, *** $p < 0.01$.

Therefore, this paper draws on the practice of Biasi and Sarsons [51], set up Mbar = 1 × standard error, to test the parallel trend sensitivity results of the policy implementation year treatment effect. It can be seen that Figure 2 under the 95% confidence interval, before the deviation degree of the parallel trend expands to 0.8 times, the role of the GSC pilot policy in improving corporate carbon performance is still significant.

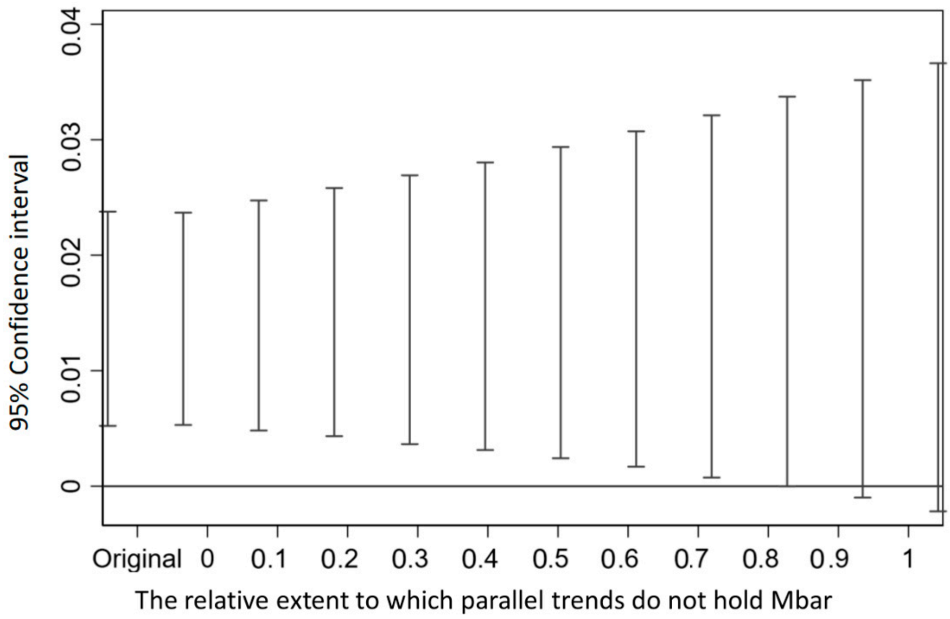

Figure 2. Parallel trend test sensitivity analysis.

4.2.2. Placebo Test

The test is to directly randomly generate the interaction term between Firm and Time for 500 times, and conduct regression for 500 times to observe whether the mean coefficient approaches 0. If it approaches 0, the estimated results of this paper are not disturbed by random factors. The Figure 3 tells us the coefficient distribution of the regression results of enterprise carbon performance. The diagram indicates that the coefficient conforms to the normal distribution approaching 0, which shows that the randomly generated sample combination has no impact on enterprise carbon performance. Thus, the results in baseline regression are robust.

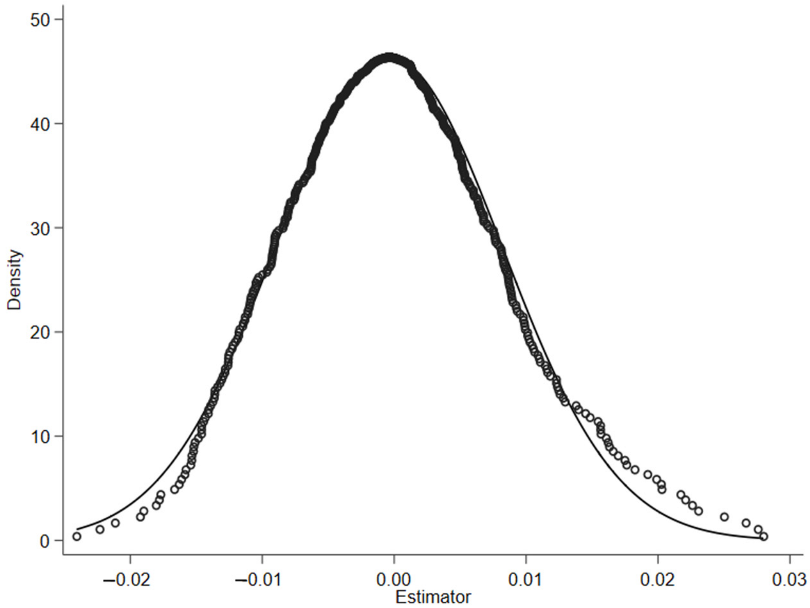

Figure 3. Placebo test.

5. The Further Analysis

5.1. Mechanism Test

What path can the GSC pilot take to promote the carbon performance of enterprises? Does the actual situation conform to the inference based on the foregoing theoretical assumptions made? To address the aforementioned issues, this article uses the following three channels to illustrate.

5.1.1. The Green Innovation Mechanism of Inspection

From our aforementioned theoretical analysis, this pilot policy may promote the improvement of corporate carbon performance through green innovation. To verify the mechanism and the findings of Xu [45], the green invention patent and green utility patent are used to measure the green innovation of enterprises. Table 5 (1), as a GSC pilot, estimates the impact of the green innovation effect. The findings indicate that the estimated coefficient of Time × Firm is significantly positive at 1%, indicating that the GSC pilot policy can strongly encourage enterprises to carry out green innovation and reduce carbon emissions. Hypothesis H1 is proved.

Table 5. Test of mechanism and moderating effect.

	(1)	(2)	(3)	(4)	(5)
Variables	**Green Innovation**	**Efficiency Improvement**	**Environmental Information Disclosure**	**Adjust the Effect**	**Environmental Attention**
Time × Firm	8.8041 *** −1.606	0.2009 ** −0.072	1.9161 *** −0.338	0.0196 *** −0.003	0.0034 *** −0.001
Time × Firm × ER				0.0660 *** −0.014	

Table 5. *Cont.*

	(1)	(2)	(3)	(4)	(5)
Variables	**Green Innovation**	**Efficiency Improvement**	**Environmental Information Disclosure**	**Adjust the Effect**	**Environmental Attention**
Time × Firm × EA					2.3241 ***
					−0.132
ER				0.1256	
				−0.015	
EA					−1.0506 ***
					−0.238
Control	YES	YES	YES	YES	YES
_cons	71.73	3.2918 ***	16.6005	2.3137 ***	2.8668 ***
	−14.822	−0.397	−5.468	−0.076	−0.021
N	20,995	20,925	20,995	20,857	20,995
r2	0.8031	0.8748	0.7631	0.7916	0.679

Note: The figures in the brackets are the robust standard errors clustered to the industry level. The data related to the control variables and the firm-year fixed effects have been controlled. ** $p < 0.05$, *** $p < 0.01$.

5.1.2. Test of the Mechanism for Improving Efficiency

According to the above analysis of the mechanism of promoting efficiency, our paper measured the efficiency of supply chain inventory turnover days. According to the proxy variable replacement regression, we can see in Table 5 that the coefficient of the first Column (2) under the 5% level is significantly positive, and the proof mechanism of the supply chain efficiency is remarkable, thus, confirming H2.

5.1.3. The EID Mechanism of Inspection

Previous analysis of the EID mechanism implies that the GSC may affect corporate carbon performance through whether the company discloses relevant environmental information in the corporate social responsibility report. Therefore, this paper uses the total EID quality score of listed companies as the proxy variable of EID for regression. Table 5 (3) shows the GSC pilot estimated results of EID. The estimated coefficient of Time × Firm is 1.916, and the coefficient is significantly positive at 1% level, that EID mechanism is significant, which confirmed the H3.

5.1.4. The Environmental Regulation Moderating Effect of Inspection

The previous analysis shows that, in the impact of GSC on corporate carbon performance, ER is indispensable, and the impact of pilot policies will be different according to the intensity of ER. Column (4) of Table 5 shows that the coefficient of interaction term between ER and GSC pilot is 0.066, which is significantly positive, consistent with the benchmark regression results, indicating that the improvement of ER level can effectively promote the carbon reduction effect of pilot enterprises, thus confirming H4. In addition, Column (5) attempts to measure the moderating effect of the government's ER from the aspect of environmental attention. The interaction coefficient between environmental attention and GSC pilot is 2.3241, which is significantly positive, indicating that the government's attention to ecology can strengthen the role of GSC and reduce greenhouse gas emissions.

5.2. Heterogeneity Test

Starting from the analysis of enterprise characteristics, this paper conducts heterogeneity tests on enterprises with different life cycles, different resource intensity, and different ownership nature.

5.2.1. Business Life Cycle

In terms of the enterprise life cycle, this paper refers to the research of Shi et al. [52] and divides enterprises into different stages according to the life cycle. In the company's growth stage, its business expansion is highly dependent on capital, and it often encounters financing problems. In order to quickly seize the market, the capital is mainly directed to capacity expansion and marketing rather than technological innovation and environmental protection investment. Maturity and recession, in contrast, companies have a stable source of funds and market position, prefer to follow the technology import, cooperate between colleges, and make R&D promote energy conservation and environmental protection to enhance their corporate image and market competitiveness.

5.2.2. Firm Resource Intensity

To investigate the carbon performance of enterprises under different resource intensities regarding the construction of GSC, we classified the enterprises into labor-intensive, capital-intensive, and technology-intensive types. The results are presented in columns (3), (4), and (5) of Table 6. The findings indicate that only technology-intensive enterprises significantly enhanced their carbon performance, meaning that the reduction of carbon emissions per unit of output achieved marked progress. This type of enterprise generally possesses advanced equipment and production processes and has the highest proportion of scientific and technical personnel. Under the implementation of the pilot policy, this type of enterprise can respond fastest to the requirements of technological emission reduction, improve energy efficiency, and simultaneously lower the level of carbon dioxide emissions. On the other hand, the carbon performance of labor-intensive enterprises was negatively significant under the implementation of the GSC pilot policy. The possible reason is that their production process is relatively dependent on a large number of labor forces in the short term, and is difficult to change the inherent production mode.

Table 6. Firm life cycle and firm resource intensity.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Business Life Cycle			**Firm Resource Intensity**		**Nature of the Enterprise**	
	Growth Period	**Maturity and Decline**	**Labor Intensive**	**Capital Intensive**	**Technology Intensive**	**State-Owned**	**Non-State-Owned**
Time × Firm	0.0075 ***	0.0076 ***	0.0185	−0.0005 ***	0.0172 ***	−0.0041 ***	0.0127 **
	−0.002	−0.003	−0.005	−0.001	−0.003	−0.001	−0.005
Control	YES	YES	YES	YES	YES	YES	YES
N	10589	10079	1830	5107	10306	6910	14037
R^2	0.7205	0.6724	0.4976	0.6933	0.6977	0.7347	0.6266

Note: The figures in parentheses are the robust standard errors clustered to the industry level, the data related to the control variables, and the firm-year fixed effects have been controlled. ** $p < 0.05$, *** $p < 0.01$.

5.2.3. Nature of the Enterprise

Regarding ownership, the coefficient of state-owned enterprises in Column (6) is negative and significant after the implementation of the pilot policy, while the coefficient of non-state-owned enterprises is 0.0127 and significantly positive. This may be because state-owned enterprises contain more heavy industries, which usually play an important role in stabilizing the national economy. However, non-state-owned enterprises may have less social responsibility before the policy implementation and be less supervised by the government, social media, and the public, so they are highly sensitive to the policy implementation and have a relatively obvious improvement in carbon performance.

To sum up, different types of enterprises, because of their different characteristics, have different performances in innovation, efficiency improvement, or EID, and ultimately, their carbon performance is better than that of other types of enterprises. First, mature and declining enterprises have stable capital flow and hope to consolidate their market position, and they will show excellent EID through scientific and technological progress. Secondly, through cooperation with schools to conduct research and development or introduce high-quality talents, technology-intensive enterprises promote technological innovation to reduce carbon emissions. Finally, non-state-owned enterprises can improve work efficiency through digital logistics, intelligent warehousing, and other means to reduce carbon production.

6. Conclusions and Suggestions

6.1. Conclusions

The GSC pilot policy is an important decision and deployment for China to promote supply chain innovation and application. We take the release of the GSC pilot as a quasi-natural experiment and use the data of A-share listed companies in China's Shanghai and Shenzhen stock markets from 2013 to 2022 to analyze whether the GSC pilot significantly reduces the carbon emissions of pilot enterprises. The findings are as follows: first, the GSC pilot policy improves the pilot enterprises' carbon performance, and it has passed a series of robustness tests. Second, it is consistent with the conclusions of existing literature on the impact of carbon emissions [37,53–55] that policy can improve the carbon performance of enterprises through three impact mechanisms: green innovation, efficiency improvement, and EID. In addition, when we test the moderating effect of ER, we find that the stronger the government's ER is and the more obvious the environmental attention is, the better the carbon emission reduction effect of enterprises is. Thirdly, from the perspective of different enterprise characteristics, GSC has a more significant effect on improving the carbon reduction of mature and declining enterprises, technology-intensive enterprises, and non-state-owned enterprises but has little effect on the carbon performance of growth enterprises, labor-intensive enterprises, and state-owned enterprises.

6.2. Limitations

This paper has the research value to further expand and follow up. Since the analyzed data are the first batch of pilot enterprises and microscopic panel data, we can explore the impact of China's GSC pilot cities at the macro level in the future to think about the deeper significance of GSC.

6.3. Policy Implications

This paper confirms the impact of GSC on carbon emissions, which can effectively provide the government with reference for ecological protection decision-making and enlightenment for enterprise development and transformation. For example: (1) The government should expand the pilot scope of GSC, summarize and publicize the first batch of practical experience that can be replicated and promoted, and promote the enterprises on, in, and downstream of the supply chain to enter the green development stage through green innovation, efficiency improvement, and EID; (2) Enterprises should make corresponding contributions to ecologically sustainable development. They should consider how to improve the level of science and technology, enhance the efficiency of the supply chain, and improve the quality of EID to achieve low-carbon development.

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