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ORIGINAL RESEARCH

The green innovation effect of the city's green supply chain pilot: evidence from a quasi-natural experiment

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Abstract
As a crucial element of management practices for green supply chains (GSC), cities' GSC pilot policies have played a vital role in mitigating environmental risks, enhancing resource utilization efficiency, and fostering sustainable urban development. Using data from A-share listed companies between 2016 and 2020, this study employs a quasi-natural experiment to the implementation of a city's GSC pilot policy to empirically investigate its influence on corporate green innovation. The findings indicate that (1) the city's GSC pilots significantly enhance enterprises' performance in terms of green innovation; (2) the positive impact of the city GSC pilots on corporate green innovation stems from heightened regulatory pressure within urban areas and increased supply chain standards; (3) this positive impact is more significant in cities with environmental laws and companies with green investors; and (4) green innovation triggered by city GSC pilots can significantly improve environmental, social, governance (ESG), and economic performance. This study offers empirical evidence for enhancing enterprises' green innovation performance, while providing theoretical support and policy insights for strengthening government-led city GSC pilot systems.

Keywords Green supply chain pilot · Green innovation · City regulation pressure · Supply chain normative pressure

1 Introduction

In recent years, traditional and non-traditional security issues, such as the Russia-Ukraine conflict, climate change, and the COVID-19 pandemic, have overlapped and continuously

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affected the global supply chain. The international community's demand for green supply chains (GSCs) based on clean energy is increasing. The International Energy Agency report, "Net Zero Emissions 2050: A Roadmap for the Global Energy Sector," states that clean energy transformation will change the structure of the global supply chain. Major global economies have made the green transformation of their economies and energy sources key elements in the quest for economic growth, combating climate change, and achieving energy security. In April 2021, the Biden Administration released "Building Resilient Supply Chains, Revitalizing U.S. Manufacturing, and Promoting Broad-based Growth," which noted the need to focus on GSC issues. At the same time, the Chinese government issued the "Guidance on Accelerating the Establishment of a Sound Green Low-Carbon Cycle Development Economic System," proposing to build a GSC and promote the green cycle of the economy. Therefore, GSCs are an important topic of concern for both governments and society.

Michigan State University pioneered the concept of the GSC. It is a supply chain management (SCM) strategy that focuses on environmental sustainability and encompasses suppliers, manufacturing facilities, distributors, and end users. This approach incorporates green manufacturing principles and utilizes SCM methodologies. This concept aims to protect the environment, improve resource utilization, and reduce organizational environmental risks by improving the design, operation, and management of the supply chain (Dickson, 1966). The literature related to GSC mainly focuses on two dimensions: GSC management practices and government intervention. In terms of the management practices implemented by the GSC, scholars focused on environmental compliance and cost control in earlier SCM research (Li et al., 2006; Walker et al., 2008). In recent years, researchers have expanded the scope of their studies on GSCs to include social responsibility, supply chain transparency, and corporate performance. Xu et al. (2022) find that corporate social responsibility significantly affects GSC management practices, which further impacts enterprise operational performance. Fahimnia et al. (2015) believe that the visualization and sharing of real-time data could help enhance the transparency and coordination ability of GSCs, which in turn promotes its efficiency. Pan et al. (2020) found that effective collaborative communication among GSC members could enhance an organization's environmental performance but constrain its economic performance. In addition, some scholars focused on green innovation research, such as Wong et al. (2020) and Qu and Liu (2022), who found that integrating a GSC can positively improve enterprises' green innovation capabilities, thus enhancing their environmental performance. Seman et al. (2019) believe that green innovation in GSC includes not only green production within companies, but also upstream green procurement and downstream green product design. From the perspective of government intervention, game theory has predominantly been employed by scholars to examine the dynamics between manufacturers, retailers, and government agencies in the context of GSC. Vermeulen and Kok (2012) conducted a comprehensive analysis of wood and coffee product chains by incorporating techniques from sustainable business and policy analyses. Their study investigated the impact of government intervention on promoting environmentally friendly transformations within supply chains. Madani and Rasti-Barzoki (2017), Mahmoudi and Rasti-Barzoki (2018), and Amiri-Pebdani (2022) employed game theory to examine the gaming conduct of GSC and the members involved in government regulation. Li et al. (2021) used game theory to study how the provision of government subsidies can facilitate the promotion of environmentally friendly changes in supply chains.

Although the existing research on GSC is relatively rich, there are still a few areas that require investigation.

First, most existing literature discusses GSC from the perspective of management practices, but none have examined the connotation of GSC management practices from the perspective of government intervention. The essence of GSC management is green innovation in the supply chain network structure (Xie & Zhu, 2022). In the process of establishing a GSC system, green innovation serves as a crucial tool to drive sustainable development and enables nodal enterprises to effectively fulfill their environmental governance obligations. Hence, examining government intervention as a lens for exploring corporate green innovation can offer valuable insights into the existing body of literature.

Second, existing literature mainly focuses on a single environmental policy from the perspective of government interventions, and reviews of comprehensive environmental policies are very limited. In addition, most existing literature uses simulation methods to determine the effect of government interventions, and there is a lack of objective data for verification. In October 2018, China's Ministry of Commerce, Ministry of Industry and Information Technology, and eight other departments jointly issued the "Notice on the Pilot Implementation of Supply Chain Innovation and Application." The document indicates that encouraging enterprises to undergo green transformation and establish eco-friendly supply chains is a crucial component in pilot cities' efforts towards sustainability. It proposes that pilot cities construct GSC from four perspectives: deepening government green procurement, establishing GSC systems, promoting the development of the environmental protection industry, and promoting green consumption. Furthermore, to accomplish the objective of fostering an eco-friendly revolution within the supply chain, urban GSC pilot programs require the implementation of whole-process green management in the supply chain, and all members within the GSC must fulfill their main responsibilities for environmental governance fully. Urban GSC pilot programs are not only a new comprehensive environmental policy, but also an exogenous policy shock. Hence, using empirical approaches to investigate the correlation between urban GSC pilot initiatives and green innovation can provide substantial empirical support for existing scholarly studies.

In summary, this study explores the impact of urban GSC pilot programs on corporate green innovation from the perspective of GSC management practices. Specifically, it addresses the following three questions: First, can urban GSC pilot programs impact corporate green innovation? Second, if such an effect exists, what is its mechanism of action? Third, do the impacts of urban GSC pilot programs on corporate green innovation vary across different characteristics? Fourth, if such an effect exists, what are the economic consequences?

To solve these problems, this study finds that city GSC pilots enhance corporate green innovation performance based on data from A-share listed companies for 2016–2020. After considering the endogeneity issue, the results still hold.

Further research indicates that the green innovation effect of the GSC pilots are more pronounced for firms situated in cities with a higher level of government attention towards environmental issues and those with a greater number of supply chain partners located within the same city. These results support the hypothesis that both regulatory pressure from cities and normative pressure within supply chains play significant roles in stimulating green innovation through GSC pilots. We also performed a heterogeneity test and established that, compared to companies in cities that do not have environmental laws and green investors, those with them are better able to increase green innovation through city GSC pilots.

This study indicates that implementing trial initiatives can provide economic advantages and promote environmentally conscious development within companies. This leads to enhancements in both ecological and social aspects, ultimately contributing to corporate success.

The possible marginal contribution of this study includes the following four aspects: First, it aims to further investigate the determinants of corporate green innovation by examining a wide range of environmental policies. Although existing literature has paid much attention to the GSC field from the perspective of government interventions, they are limited to single environmental policies, such as emission trading pilot policies (Chen et al., 2022; Du et al., 2021a, 2021b), environmental taxes (Karmaker et al., 2021), and government green procurement (Simcoe & Toffel, 2014; Al Nuaimi, 2021) on the promotion effect of corporate green innovation. Additionally, some studies have examined the influence of comprehensive environmental policies on corporate green innovation using low-carbon city pilot studies (Pan et al., 2022). However, this study focuses on government governance and starts with GSC pilot programs, which aim to build a whole GSC system process to study how GSC pilot programs affect the quantity and quality of corporate green innovation, thus contributing to the broadening of scholarly research on the determinants of green innovation in corporations.

Second, from the perspective of urban and supply chain regulation pressures, this study examines the mechanism by which urban GSC pilots affect enterprises' green innovation. The existing literature mainly discusses the role of government interventions in the green transformation of supply chains through the game evolution method (Li et al., 2021; Amiri-Pebdani, 2022); there are no studies that clearly depict the internal path and mechanism of urban GSC pilots' affect on enterprises' green innovation. This study conducted an empirical test by constructing a triple-difference model, revealing the veil of this process, and contributing to the improvement of urban GSC pilot policies. More effectively, it promotes urban GSC pilot policies and provides optimization paths.

Third, this study examines the heterogeneity of the relationship between urban GSC pilots and enterprise green innovation from the perspective of enterprises and cities. It shows that the implementation effect of the current urban GSC pilot is still restricted by objective conditions, and this conclusion provides a reference for governments to implement accurate policies.

Fourth, this study enhances the investigation of the economic implications of green innovation in enterprises. Green innovation among supply chain members is an important issue in GSC. Most existing studies believe that the promotion of green innovation by enterprises will improve environmental and reduce economic performance (Qu & Liu, 2022; Wong et al., 2020). However, this study shows that corporate green innovation triggered by GSC pilots can improve both corporate environmental and economic performance, offering fresh insights into scholarly research on the financial outcomes of environmentally friendly advancements in businesses.

2 Institutional background

In 2018, a collaborative effort by the Chinese Ministry of Commerce, along with the Ministry of Ecology and Environment and other relevant departments, issued a notification titled "Pilot Implementation of Supply Chain Innovation and Application." The Notice lists the construction of GSCs as a key task to guide localities and business organizations to practice the idea of green development and promote the improvement of ecological and environmental quality.

According to this document, a pilot city should build the GSC from four perspectives: First, they must deepen government green procurement, emphasizing the importance of prioritizing the acquisition and utilization of products, equipment, and facilities that promote energy, water, and material conservation, as well as other eco-friendly alternatives. In addition, an evaluation system should be established to align these principles. Second, such cities should establish a GSC system, study and develop a GSC construction guide for key industrial enterprises, establish and improve environmental credit evaluations, have mandatory disclosure of information and other systems, and adhere to legal requirements by providing details regarding environmental infractions across the entire supply network. Third, the pilot cities should promote the development of the environmental protection industry. Finally, they should promote green consumption, increase the publicity of green products and packaging, encourage the development of the courier and recycling industries in direct cooperation, guide the pursuit of nature-friendly goals, pursue a healthy consumer philosophy, and cultivate a green consumer market.

After the document was issued, the pilot cities released specific opinions on local implementation based on the spirit of the document. For example, Shanghai proposed selecting a number of leading enterprises in the automotive, electronics and electrical appliances, communications, machinery, large sets of equipment, and other industries; establishing a sustainable green supply chain management (GSCM) strategy for enterprises; implementing green partner supplier management; prioritizing the inclusion of green factories as qualified suppliers and procurement of green products; strengthening green production; building a green information management platform for the supply chain; and encouraging both upstream and downstream businesses to embrace green growth. Ningbo proposed the cultivation of several GSCM demonstration enterprises using large sets of equipment and other industries. Tianjin proposed the promotion of GSCM in the automotive, electrical, and electronic communications, large sets of equipment and machinery, and other industries. Additionally, to carry out GSCM demonstrations, enhance the marketing and adoption of alternative fuel vehicles, facilitate the integration of new energy vehicle enterprises into the regulatory platform, improve new energy vehicle subsidy clearing, and conduct new energy vehicle theme promotion activities.

3 Hypothesis development

3.1 GSC pilot and green innovation: a city regulatory pressure perspective

Neo-institutionalist theory uses "legitimacy" to explain business behavior decisions. The theory argues that individual and organizational behavior is driven not only by individual intentions and motivations, but also by the institutional environment and influence of stakeholders. To gain resource support from the latter, individuals and organizations adopt appropriate behavioral strategies to gain institutional legitimacy (DiMaggio and Powell, 1983). According to this hypothesis, the government has significant influence on the institutional environment. When the government conducts GSC pilots and builds GSCs as important evaluation indicators of corporate legitimacy and reputation, it creates regulatory legitimacy pressure on the focal companies. Such pressures are a variety of formal or informal regulatory pressures exerted on an organization by an authoritative or coercive body to force it to adopt a certain structure or behavior. For example, the government sets requirements and standards for pollution prevention and control or environmental protection for specific enterprises, conducts regular inspections and assessments of daily environmental performance, and provides rewards and punishments based on environmental management performance (Li et al., 2018). Faced with serious legal sanctions and the high costs of violating relevant environmental regulations, companies will proactively adopt innovative green technologies to enhance the credibility of regulations. Zhang et al. (2020) established that environmental regulation is the most important external pressure affecting firms' green innovation. Avoiding mandatory regulations, such as warnings, monitoring, or penalties, is an important driver for firms to adopt green innovation. According to the study conducted by Du et al., (2021a, 2021b), government regulations encourage firms to pursue green technological innovation. Currently, firms are confined to their existing traditional products and technologies, have high organizational inertia, and often lack incentives for green innovation (Ren et al., 2022). The "Notice on the Piloting of Supply Chain Innovation and Application" states that pilot cities should establish and improve environmental credit evaluations and adhere to legal requirements by providing details regarding environmental infractions across the entire supply network. Therefore, pilot cities will take the initiative to exert pressure on regulatory legitimacy and enforce penalties on businesses that fail to comply with environmental regulations. According to the aforementioned theory, enterprises are highly motivated to participate in green innovation to improve environmental legitimacy and avoid political risks and legal sanctions. However, owing to the presence of elevated risk and limited short-term profitability, there is a reluctance to invest heavily in green innovation, and the green technology R&D process is relatively complex and novel. Even if firms have sufficient motivation for green innovation, they may stagnate because they cannot afford to bear the cost of risks alone. In China, during the transition period, the government still controls the allocation of scarce resources. In addition to mandatory regulations, such as regulatory penalties, the government can also provide green innovation resources, establish an environment of business regulation, and minimize the expenses and uncertainties associated with green innovation for enterprises through incentive-based and supportive regulations, thereby attracting companies to implement such innovations. Xia et al. (2022) demonstrate the pivotal role of government subsidies in stimulating green innovation within enterprises. According to the "Notice on the Piloting of Supply Chain Innovation and Application," pilot cities need to deepen government green procurement, prioritize the procurement, use, and sustainability of energy, water, materials, and other environmentally friendly products, equipment, and facilities, and establish a corresponding assessment system. Pilot cities subsidize green procurement or products, thus alleviating the inability of enterprises to engage in green innovation due to a lack of funding.

3.2 GSC pilot and green innovation: a supply chain normative pressure perspective

According to neo-institutionalist theory, organizations are motivated by the environmental orientation of corporate supply chain partners to implement green practices, thus creating normative legitimacy pressure on the focal firm. To gain access to the resources provided by stakeholders, companies try to maintain the same standards of behavior, norms, and social expectations as members of the same institutional environment to gain legitimacy (Singh et al., 2022). Du et al. (2018) also found that normative legitimacy pressures, including those of customers, suppliers, and non-governmental organizations (NGOs) advocating environmental norms and green standards, can contribute positively to the implementation of green innovation practices within corporations. Compared to other environmental regulation pilots, a key feature of the GSC pilot is the use of industry leaders to take the lead. Using the green procurement of large enterprises to implement regulatory legitimacy pressure on supply chain partners will effectively encourage upstream and downstream enterprises to implement green innovation practices. Shanghai, a pilot city, has proposed the selection of several leading enterprises to establish a sustainable GSCM strategy and implement green partner supplier management. After implementing GSCM, core enterprises will take green awareness and technology and prioritize the procurement of products with excellent environmental performance or utilization of renewable resources, using equipment and facilities as the primary evaluation indicators. Simultaneously, supply chain members who meet environmental legality requirements are given policy benefits, such as accounts payable extensions and price concessions (Agi et al., 2021; Chen et al., 2017). When core supply chain companies have green product preferences, the requirements for the focal company's environmental ethics and product environmental utility legitimacy are higher. To cope with the increasingly stringent pressure of supply chain norms, local companies should actively participate in the innovation of green technologies so that their green capabilities and product quality meet the requirements of core companies. Therefore, we formulate the following hypotheses:

H1 GSC pilots can improve firms' green innovation.

4 Research design and data

4.1 Sample and data

To establish a GSC, a pilot project on supply chain innovation and application was conducted in 2018 by the Ministry of Commerce, along with eight additional departments. A total of 55 pilot cities were selected, and the scheme stated to "vigorously advocate green manufacturing, actively promote green circulation, establish a reverse logistics system and other ways to build a green supply chain" as the main task of the pilot enterprises. A pilot program for implementing innovative supply chain practices can be considered a quasi-natural experiment. To assess the influence of the GSC pilot on enterprises' green innovation, we used the double-difference method, with enterprises in pilot cities as the experimental group and those in non-pilot cities as the control group, to judge the impact of pilot policies on green innovation. Considering the necessity for consistency in the sample periods before and after policy implementation, we have opted to initially concentrate our research on A-share listed companies in Shanghai and Shenzhen from 2016 to 2020, given that the pilot was officially launched in October 2018. The sample was screened as follows: (1) to exclude financial enterprises and (2) to exclude missing data and obvious abnormal samples. Finally, we obtain 11,955 firm-year observations, including 5730 and 6225 for the control and experimental groups, respectively. The data used in this study were obtained from the CSMAR database, and all continuous variables were subjected to a 1% Winsorization procedure.

4.2 Variables

4.2.1 Dependent variables

Existing literature has shown that patents are an effective tool for measuring technological innovation and the results of innovation activities (Peng et al., 2023). Statistical data on the number of patent applications can translate intermediate products into innovation activities (Jalles, 2010). Therefore, this study used the number of green patent applications to measure an enterprise's green innovation performance. We specifically consolidate the number of patent applications pertaining to green inventions and utility models to ascertain the overall number of green innovations (GIS). Given that the number of patent applications for green inventions encompasses a substantial degree of technical complexity, it serves as an indicator of the caliber of green innovation (GIZ).

4.2.2 Independent variables

This study uses the double-difference method to investigate whether a GSC pilot can improve the green innovation performance of enterprises. The experimental group consisted of enterprises whose cities were selected as pilots (treatment = 1), and the control group included those whose cities were not selected (treatment = 0).

4.2.3 Control variables

Existing studies (Wang et al., 2021; Singh et al., 2022; Peng et al., 2023) believe that corporate green innovation will be affected by other explanatory variables, such as financial characteristics, capital structure, firm size, and attributes. The influence of these variables was controlled to ensure the effectiveness of the regression model. In addition, these control variables are selected for the following reasons: Return on assets (Roa) reflects the profitability of an enterprise, and the more revenue an enterprise has, the more likely it is to invest resources in green innovation activities; Asset-liability ratio (Lev) can assess the financial risk of enterprises. When the value of Lev is high, enterprises will be cautious about green innovation behavior when considering risk control; when the value of Lev is low, enterprises will have more equity financing and are more likely to bear the initial costs and risks of green innovation activities. Enterprises with larger size and age variables usually have more mature internal processes and more resources, so they can carry out green innovation more easily. According to the agency theory, when the management shareholding ratio (Mngmhldn) and degree of Dual are high, the top managers are more inclined to pursue short-term profits and satisfy the short-term goals of shareholders, which leads to a lack of interest in long-term strategies, such as green innovation. Institutional investors are generally more focused on long-term value and sustainability, so are more inclined to support a company's green innovation strategy. In addition, for the variable of the proportion of institutional investors (Insinvestorprop), institutional investors have more resources and expertise, and can provide more support and guidance to promote the green innovation of enterprises. In the case of state ownership (State), ownership and management are often controlled by the government, so they may be more inclined to pursue green innovation with social and environmental benefits rather than financial benefits alone.

4.3 Regression model

To quantitatively examine the impact of city GSC pilots on firms' green innovation performance, we set the two-stage least squares regression model (2SLS) as follows:

$$
\begin{aligned}
Y_{i,t} &= \alpha_0 + \alpha_1 Treat_i \times Post_{i,t} + \alpha_2 Treat_i + \alpha_3 Post_{i,t} + \sum Controls \\
&+ \sum Year + \sum Industry + \sum City
\end{aligned} \tag{1}
$$

The explanatory variable $Y_{i,t}$ denotes the green innovation performance of enterprise i in year t. The core explanatory variable $Treat_i$ is the grouping variable; the enterprise is assigned a value of 1 for the pilot city, otherwise 0. Controls are the control variables, and Industry, Year, and City denote industry, year, and city fixed effects, respectively. This study evaluates the efficiency of a pilot program for GSCs by assessing treatment-based coefficients. When the coefficient is positive, H1 (that a GSC pilot program can enhance the efficiency of green innovation in businesses) is verified (Table 1).

Table 1 Variable definitions

Variable	Definition
Dependent variables	
GIS	The number of green innovations of enterprises, expressed by the total number of green patent applications.
GIZ	The quality of green innovation of enterprises, expressed by the total number of green invention patent applications.
Independent variables	
Treatpost	Whether it belongs to the green supply chain pilot.
Control variables	
Roa	Return on assets, equal to year-end net income divided by average net assets.
Lev	Gearing ratio, equal to net profit after tax / total assets.
Size	Firm size, defined as the natural logarithm of issuers by average ne.
Age	Enterprise age, defined as current age minus listing age.
Mngmhldn	Management shareholding ratio.
Dual	Indicates the separation of the two positions; if the chairman and general manager are not the same person then it is equal to 1, otherwise 0.
Insinvestorprop	Percentage of institutional investors.
State	Indicates the nature of property rights, state-owned is 1, non-state-owned is 0.

5 Results

5.1 Data and summary statistics

Table 2 presents statistical information on the primary variables. The average values for the overall quantity of green patents and the number of green invention patents held by listed companies were 6.311 and 2.016, respectively, while both middlemost values were 0. This indicates a low presence of green patents in China, with over half of the listed companies showing no green innovation output during the sample period. There is scope for improvement in the overall level of green innovation. The average value of green invention patents is significantly below the overall average value of green patents, indicating that it is difficult to obtain green invention patents. Therefore, the level of green innovation can be measured by green invention patents. The distribution characteristics of the remaining variables are similar to those in previous studies and are repeated here.

5.2 Regression result analysis

The green innovation effect of the city's GSC pilot program is presented in Table 3. The results in columns (1) and (2) indicate that the Treat × Post coefficients of the cross-multiplication term between the grouping and treatment group variables are 1.619 and 0.62 when there is no control for city fixed effects and are significant at the 1% and 5% levels, respectively. The results in columns (3) and (4) show that, after not controlling for city fixed effects, the Treat × Post coefficients of the cross-product term between the grouping and treatment group variables are 0.553 and 0.788, respectively, and both are significant at the 1% level, suggesting

Table 2 Description statistics

Variable	N	Full sample (sample size 11955)			Control group (sample size 5730)			Experimental group (sample size 6225)		
		Mean	Meidian	Sd	Mean	Meidian	Sd	Mean	Meidian	Sd
GIS	11,955	6.311	1.000	34.560	4.642	0.000	19.610	7.849	1.000	43.990
GIZ	11,955	2.016	0.000	18.590	1.102	0.000	5.999	2.856	0.000	25.080
Size	11,955	22.180	22.030	1.236	22.110	21.980	1.158	22.250	22.060	1.301
Roa	11,955	0.044	0.044	0.071	0.0454	0.044	0.070	0.043	0.043	0.072
Insinvestorprop	11,955	40.990	42.010	24.950	40.440	41.560	24.430	41.510	42.690	25.410
Dual	11,955	0.675	1.000	0.468	0.678	1.000	0.467	0.673	1.000	0.470
Mngmhldn	11,955	6.571	0.040	12.320	6.239	0.030	12.250	6.876	0.0500	12.380
Lev	11,955	0.399	0.387	0.197	0.392	0.378	0.196	0.406	0.396	0.198
State	11,955	0.287	0.000	0.452	0.258	0.000	0.437	0.314	0.000	0.464
Age	11,955	10.170	8.326	7.810	10.100	8.425	7.555	10.230	8.227	8.038

Table 3 Baseline estimations results

Variables	(1)	(2)	(3)	(4)
	GIS	GIZ	GIS	GIZ
Treat×Post	1.619*** (3.05)	0.620** (2.58)	1.605*** (3.01)	0.628*** (2.60)
Post	1.867 (0.26)	− 2.744 (− 0.84)	2.338 (0.31)	− 3.010 (− 0.88)
Treat	− 1.897 (− 0.56)	− 0.199 (− 0.13)	− 12.318 (− 0.41)	0.272 (0.02)
Lev	− 7.297*** (− 3.46)	− 2.144** (− 2.24)	− 7.063*** (− 3.32)	− 2.139** (− 2.22)
Size	2.865*** (4.58)	0.415 (1.46)	2.793*** (4.44)	0.390 (1.37)
Dual	2.358*** (3.67)	0.936*** (3.21)	2.385*** (3.69)	0.952*** (3.24)
Mngmhldn	0.132*** (3.88)	0.050*** (3.23)	0.133*** (3.91)	0.050*** (3.23)
Roa	− 4.755 (− 1.52)	− 2.489* (− 1.76)	− 4.734 (− 1.50)	− 2.479* (− 1.73)
State	− 0.709 (− 0.55)	− 0.215 (− 0.36)	− 0.739 (− 0.56)	− 0.221 (− 0.37)
Age	0.696 (0.39)	0.890 (1.10)	0.574 (0.31)	0.956 (1.12)
Insinvestorprop	0.060** (2.36)	0.025** (2.19)	0.059** (2.30)	0.025** (2.14)
Constant	− 65.662*** (− 3.30)	− 15.025* (− 1.67)	− 58.659*** (− 2.62)	− 15.396 (− 1.52)
Observations	11,955	11,955	11,955	11,955
R-squared	0.047	0.010	0.051	0.011
Industry FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
City FE	NO	NO	YES	YES

t-statistics are in parentheses

*, **, and *** = $p < 0.1$, $p < 0.05$, and $p < 0.01$, respectively

that the implementation of the GSC pilot program improves firms' green innovation performance. Regarding their economic meaning, in columns (3) and (4), compared to enterprises in cities without GSC pilot programs, those in cities with such programs increased their total and invention-based green patents by 1.605 and 0.628, respectively, indicating that such pilot programs can improve enterprises' green innovation performance.

5.3 Robustness test

5.3.1 Parallel trend test

To test whether the urban GSC pilot program had an effective exogenous policy impact, this study conducted a parallel trend test. After expanding the sample period to 2013–2020, we used 2018 as the base period and constructed the time dummy variables Pre_2, Pre_3, Pre_4, and Pre_5, which take the values of 1 in 2016, 2015, 2014, and 2013, respectively, and 0 for the other years. We constructed the time dummy variables Current, Post_1, and Post_2, which take the values of 1 in the current period when the policy occurs, one year after the policy occurs, and two years after the policy occurs, respectively. Table 4 presents the results of the study. Regarding the quantity of green innovation, the regression coefficients of Pre_2, Pre_3, Pre_4, and Pre_5 are insignificant, whereas those of Current, Post_1, and Post_2 are all significantly positive. For green innovation quality, the regression coefficients of Pre_2, Pre_3, Pre_4, Pre_5, and Current are not significant, whereas those of Post_1 and Post_2 are significantly positive. This finding suggests that the parallel trend hypothesis holds true.

Table 4 Parallel trend test

Variables	(1) GIS	(2) GIZ
Pre_5	− 0.424 (− 0.51)	− 0.585 (− 1.37)
Pre_4	− 0.745 (− 1.10)	− 0.580 (− 1.54)
Pre_3	− 0.880 (− 1.18)	− 0.359 (− 0.97)
Pre_2	− 0.342 (− 0.71)	0.057 (0.21)
Current	0.742** (2.47)	0.082 (0.76)
Post_1	0.944** (2.47)	0.459** (2.26)
Post_2	2.174*** (2.81)	0.693** (2.27)
Constant	− 92.251*** (− 6.79)	− 28.579*** (− 4.07)
Observations	23,441	23,441
R-squared	0.158	0.120
Industry FE	YES	YES
Year FE	YES	YES
City FE	YES	YES

t-statistics are in parentheses

*, **, and *** = $p < 0.1$, $p < 0.05$, and $p < 0.01$, respectively

5.3.2 Placebo test

To further increase the robustness of the research outcomes, we randomly drew the same number of enterprises from the full sample as the experimental group according to the number selected as pilots in the cities where they are located each year. Furthermore, we used Eq. (1) to estimate the green innovation effect of city GSC pilots and repeated it 1000 times. The coefficient distributions of treatment innovation are illustrated in Figs. 1 and 2. The results indicate that the coefficients are concentrated around 0, providing evidence that the introduction of the urban GSC pilot led to enhanced levels of green innovation achievements.

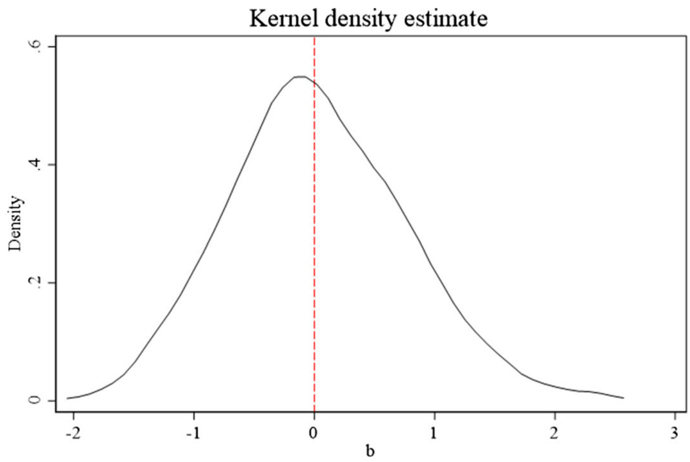

Fig. 1 Placebo test (GIS)

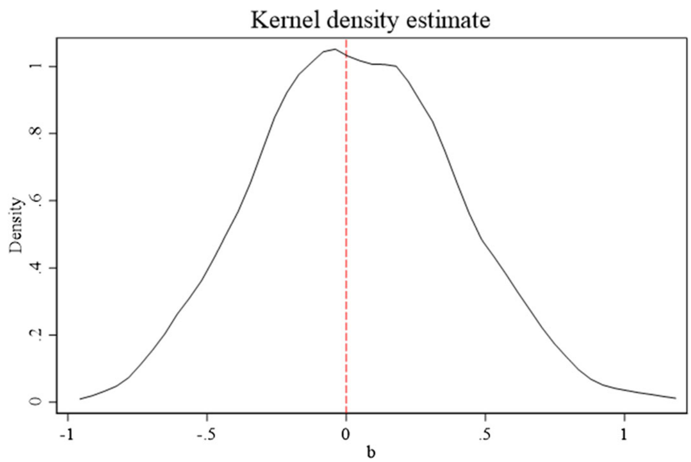

Fig. 2 Placebo test (GIZ)

Table 5 Balance test for propensity score-matched samples

Variables	Mean		Comparison	t-test
	Treated	Control	Difference(%)	P statistic
Size	22.238	22.224	1.1	0.537
Lev	0.405	0.408	− 1.5	0.415
Roa	0.0428	0.0423	0.7	0.708
Age	10.233	10.179	0.7	0.703
State	0.312	0.306	1.4	0.460
Dual	0.672	0.661	2.5	0.165
Insinvestorprop	41.417	41.057	1.4	0.427
Mngmhldn	6.891	7.164	− 2.2	0.236

5.3.3 Propensity score matching test

To correct for possible self-selection problems in the sample, this study uses whether the group is a treatment group (Treat, with the treatment group assigned a value of 1 and the control group assigned a value of 0) as the explanatory variable, and all control variables in the empirical model as control variables, with the Probit model for proximity matching. The results of the balanced tests in Table 5 revealed the differences in firm characteristics between the two matched samples. The absolute value of the difference in means did not exceed 5%, and none of the P-statistics of the t-test reached 10%, proving that the variances among the companies in both the treatment and control groups fell within permissible boundaries, indicating a good matching effect.

The regression outcomes for the propensity score-matched sample are presented in columns (1) and (2) of Table 6. The correlation coefficients between GSC pilots and the quantity and quality of green innovation in cities are statistically significant at the 5% level, indicating a strong positive association between GSC pilots and corporate green innovation. These results are consistent with the baseline empirical results and further validate H1.

5.3.4 Substitution of explanatory variables

The proportion of green patent applications to the total patent applications in the same year and the proportion of green invention patent applications to the total invention patent applications in the same year were used as substitute variables for the quantity and quality of green innovation, as represented by GIS_robust and GIZ_robust. Columns (3) and (4) of Table 6 show the regression results after replacing the dependent variable, which is consistent with the baseline empirical findings.

5.3.5 Adding control variables

Considering the possible omitted variable problem, we added the variables of the city's per capita GDP level (Gdp), population size (Pop), percentage of independent directors of the firm (Inddirectorratio), and number of corporate boards (Board) to Model (1). The regression results indicate that H1 holds true, as shown in columns (5) and (6) of Table 6.

Table 6 Robustness test

Variables	Propensity score matching test		Substitution of explanatory variables		Adding control variables	
	(1)	(2)	(3)	(4)	(5)	(6)
	GIS	GIZ	GIS_robust	GIZ_robust	GIS	GIZ
Treat×Post	0.881** (2.08)	0.507** (2.45)	0.078*** (2.83)	0.041** (2.25)	2.115*** (2.95)	0.605* (1.83)
Post	3.518 (0.61)	− 2.539 (− 0.91)	0.419 (1.04)	− 0.191 (− 0.72)	− 6.820 (− 0.76)	− 2.798 (− 0.68)
Treat	− 1.573 (− 0.58)	− 0.141 (− 0.11)	− 0.411 (− 0.47)	− 0.158 (− 0.29)	− 3.132 (− 0.51)	− 0.781 (− 0.28)
Lev	− 6.096*** (− 3.61)	− 1.962** (− 2.38)	0.184 (1.61)	− 0.052 (− 0.69)	− 7.640*** (− 2.77)	− 1.910 (− 1.50)
Size	3.411*** (6.82)	0.527** (2.16)	− 0.093*** (− 2.71)	− 0.043* (− 1.91)	3.070*** (3.82)	0.548 (1.48)
Dual	2.333*** (4.54)	0.931*** (3.71)	0.030 (0.89)	0.032 (1.39)	1.293 (1.55)	0.467 (1.21)
Mngmhldn	0.123*** (4.55)	0.048*** (3.63)	0.000 (0.15)	− 0.000 (− 0.03)	0.111** (2.43)	0.020 (0.93)
Roa	− 5.844** (− 2.34)	− 2.578** (− 2.11)	0.074 (0.43)	− 0.071 (− 0.63)	− 3.977 (− 0.97)	− 2.847 (− 1.51)
State	− 0.428 (− 0.41)	− 0.158 (− 0.31)	− 0.008 (− 0.12)	0.050 (1.14)	0.823 (0.47)	0.205 (0.26)
Age	0.134 (0.09)	0.804 (1.15)	− 0.020 (− 0.19)	0.067 (1.01)	2.769 (1.23)	0.834 (0.80)
Insinvestorprop	0.060*** (2.94)	0.022** (2.26)	0.001 (0.67)	0.000 (0.22)	0.024 (0.72)	0.024 (1.60)
Pop					− 0.000 (− 0.07)	0.001 (0.41)
Gdp					− 0.000 (− 1.06)	− 0.000 (− 0.40)
Inddirectorratio					− 0.063 (− 0.78)	− 0.118*** (− 3.15)
Board					− 4.416 (− 1.56)	− 4.139*** (− 3.16)

Table 6 (continued)

Variables	Propensity score matching test		Substitution of explanatory variables		Adding control variables	
	(1)	(2)	(3)	(4)	(5)	(6)
	GIS	GIZ	GIS_robust	GIZ_robust	GIS	GIZ
Constant	− 73.747*** (− 4.64)	− 16.729** (− 2.16)	2.269** (2.07)	0.549 (0.76)	− 68.294*** (− 2.62)	− 4.031 (− 0.33)
Observations	11,935	11,935	10,033	9,134	8,306	8,306
R-squared	0.062	0.012	0.085	0.021	0.044	0.010
Industry FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
City FE	YES	YES	YES	YES	YES	YES

5.4 Mechanism test

5.4.1 City regulatory pressure

First, we tested whether a city's GSC pilot directly influences firms' green innovation performance by exerting government regulatory pressure. Government work reports serve as a blueprint for the lawful execution and implementation of decisions and resolutions made by the governing body, functioning as strategic documents to steer government operations (Chen & Chen, 2018). Therefore, the use of environment-related vocabulary in government work reports can serve as a more accurate indicator of the effectiveness and comprehensiveness of government environmental management policies. If the city regulatory pressure hypothesis is valid, then city-level government work reports will exhibit a greater prevalence and ratio of terms related to the environment (for word frequency indicators, see Appendix 1), city regulatory pressure on enterprises will be stronger, and the green innovation effect of the city GSC pilot will be more significant. Based on Model (1), the city-level government work report environmental word frequency variable count was added to construct a triple-difference model, as follows:

$$
\begin{aligned}
Y_{i,t} &= \beta_0 + \beta_1 Treat_i \times Post_{i,t} \times Count_{i,t} + \beta_2 Treat_i \times Count_{i,t} + \beta_3 Post_{i,t} \times Count_{i,t} \\
&+ \beta_4 Post_{i,t} \times Treat_i + \beta_5 Post_{i,t} + \beta_6 Treat_i + \sum Controls + \sum Year \\
&+ \sum Industry + \sum City
\end{aligned} \tag{2}
$$

where *Count* represents the number of environmental keywords found in government work reports at the municipal level. In addition, we examined Count robust, which is the ratio of the number of environmental keywords to the total word count in the government work report.

The regression results are presented in Table 7. The coefficients of the triple-difference term are significantly positive in columns (1)–(4), indicating that the city's GSC pilot policy promotes enterprises' green technological innovation through city regulatory pressure, which verifies the city regulatory pressure hypothesis.

5.4.2 Supply chain normative pressure

Additionally, supply chain regulation pressure can indirectly influence the effect of urban global supply chain pilot policies on enterprises' green innovation performance. This study argues that if normative supply chain pressure exists, the more supply chain partners in the same city as the firm when the city is selected as a pilot, the stronger the pressure. In this case, the green innovation effect of the city's GSC pilot program was more significant. Based on Model (1), we added the number of supply chain partners in the same city at the enterprise level to construct a triple-difference model, as follows:

$$
\begin{aligned}
Y_{i,t} &= \beta_0 + \beta_1 Treat_i \times Post_{i,t} \times Partner + \beta_2 Treat_i \times Partner_{i,t} + \beta_3 Post_{i,t} \times Partner_{i,t} \\
&+ \beta_4 Post_{i,t} \times Treat_i + \beta_5 Post_{i,t} + \beta_6 Treat_i + \sum Controls + \sum Year \\
&+ \sum Industry + \sum City
\end{aligned} \tag{3}
$$

Table 7 City regulatory pressure test

Variables	(1)	(2)	(3)	(4)
	GIS	GIZ	GIS	GIZ
Count×Treat×Post	0.068*** (3.64)	0.017* (1.67)		
Count_robust×Treat×Post			763.105*** (4.10)	256.921*** (2.58)
Constant	− 205.682*** (− 26.25)	− 76.593*** (− 18.27)	− 206.267*** (− 26.17)	− 76.743*** (− 18.20)
Observations	10,829	10,829	10,829	10,829
R-squared	0.192	0.204	0.191	0.204
Control	YES	YES	YES	YES
Industry FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
City FE	YES	YES	YES	YES

t-statistics are in parentheses. *, **, and *** = $p < 0.1$, $p < 0.05$, and $p < 0.01$, respectively

Table 8 Supply chain normative pressure test

Variables	(1) GIS	(2) GIZ	(3) GIS	(4) GIZ
Partner_sup × Treat × Post	6.890*** (3.43)	1.191*** (2.59)		
Partner_pur × Treat × Post			4.242** (2.11)	0.520 (1.20)
Constant	− 82.036*** (− 9.32)	− 14.759*** (− 7.33)	− 74.603*** (− 8.79)	− 13.348*** (− 7.31)
Observations	1,351	1,351	1,599	1,599
R-squared	0.341	0.225	0.313	0.214
Control	YES	YES	YES	YES
Industry FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
City FE	YES	YES	YES	YES

t-statistics are in parentheses
*, **, and *** = $p < 0.1$, $p < 0.05$, and $p < 0.01$, respectively

In the regression, Partner_sup and Partner_pur are the number of suppliers and customers in the same city, respectively.

The regression results are presented in Table 8. The coefficients of the triple-difference term are significantly positive in columns (1) to (3), and the results in column (4) are not significant; however, the coefficients are still positive, indicating that the city GSC pilot policy promotes enterprises' green technological innovation through supply chain normative pressure, which verifies the supply chain normative pressure hypothesis.

5.5 Heterogeneity test

5.5.1 Impact of green investors

Although city GSC pilots can provide sufficient financial support to enterprises, green innovation has a low probability of success owing to the difficulty in R&D; hence, it often requires relevant background knowledge. Unlike general institutional investors, green investors have a background in environmental protection and can provide the necessary information, technology, and resources for enterprises' green innovation with their value investment vision and green knowledge reserves, which can lead to a better and faster transformation of basic green knowledge into green technological innovation (Jiang et al., 2021). For example, green investors can help enterprises contact environmental technology experts in relevant fields and representatives of green industry entities for consultations on green innovation. Additionally, they can inject advanced green innovation management models into enterprises, which can optimize the allocation of green innovation resources and increase the success rate of green innovation R&D (Chi et al., 2023). Therefore, compared to firms without green investors, those with them tend to make more effective use of the resources provided by GSC pilots for green technological innovation.

Based on the benchmark Model (1), the overall sample was divided into two subsamples (the presence and absence of green investors) to further investigate whether the GSC pilot has heterogeneous green technological innovation effects on different types of corporate entities. The calculation of green investors is based on Jiang et al. (2021), and the "investment target"

Table 9 Green investor heterogeneity test

Variables	GIS		GIZ	
	(1)	(2)	(3)	(4)
	Green investors exist	No green investors	Green investors exist	No green investors
Treat×Post	5.104** (2.30)	0.085 (0.28)	3.098*** (2.90)	− 0.133 (− 1.11)
Constant	31.254 (0.34)	− 20.624* (− 1.75)	11.351 (0.25)	− 0.858 (− 0.18)
Observations	4,042	7,913	4,042	7,913
R-squared	0.086	0.086	0.038	0.008
Control	YES	YES	YES	YES
Industry FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
City FE	YES	YES	YES	YES
Suest test	6.97***	13.40***		

t-statistics are in parentheses
*, **, and *** = $p < 0.1$, $p < 0.05$, and $p < 0.01$, respectively

and "investment scope" of the fund are determined according to the keywords. If there are investments in "low carbon," "green," "conservation," "clean energy," and so on (see Appendix 2), the company is considered a "green investor." If such investment funds exist in a stock company, there are green investors in the company.

Table 9 presents the estimation results. After simultaneously controlling for the three fixed effects, the coefficients of the double-difference term are significantly positive in columns (1) and (3), corresponding to the presence of the green investor subsample, whereas they are not significant in columns (2) and (4), corresponding to the absence of the subsample. This result indicates that green investors can help firms utilize GSC pilots more efficiently, and thus achieve substantial green innovation performance. The Suest test values are all significant, indicating that the impact of city GSC pilot projects on firms' green innovation differs significantly across the sample of green investors.

5.5.2 Impact of city environmental laws

The establishment of an ecological civilization relies heavily on the legal system, and the successful execution of the GSC pilot project is closely intertwined with legislative measures. Over the past four decades, legislators have enacted environmental protection laws in over 100 countries and regions. Notably, China's legislative authority for environmental legislation was expanded to encompass all municipalities following a 2015 amendment to their legislative law. Consequently, the legal framework for city-level environmental protection has been progressively enhanced. In the absence of environmental protection legislation, even if cities are selected as GSC pilots, the government lacks a strong grip to punish companies that violate relevant environmental regulations; thus, regulatory pressure is greatly reduced (Zhang et al., 2023). Cities have enacted environmental protection regulations to punish enterprises for environmental pollution and compensate them for ecological protection through mandatory legal means, thereby providing a stable guarantee for the effective implementation of GSC pilots.

Based on the baseline Model (1), the overall sample is divided into two subsamples: cities that enact environmental regulations and those that do not investigate further into whether city GSC pilots have a heterogeneous green technological innovation effect on firms.

Table 10 City environmental laws heterogeneity test

Variables	GIS		GIZ	
	(1) Cities enact environmental laws	(2) Cities do not enact environmental laws	(3) Cities enact environmental laws	(4) Cities do not enact environmental laws
Treat×Post	1.532** (2.18)	− 1.111 (− 0.54)	0.827** (2.40)	0.052 (0.05)
Constant	− 67.690*** (− 2.66)	− 230.708 (− 0.65)	− 18.253 (− 1.46)	28.373 (0.16)
Observations	9,242	1,351	9,242	1,351
R-squared	0.051	0.029	0.011	0.018
Number of symbol	3,287	726	3,287	726
Control	YES	YES	YES	YES
Industry FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
City FE	YES	YES	YES	YES
Suest test	6.82***	5.04**		

The t-statistics are in parentheses
$*p < 0.1$, $**p < 0.05$, and $***p < 0.01$

The estimation results are presented in Table 10. After simultaneously controlling for the three fixed effects, the coefficients of the double-difference term are significantly positive in columns (1) and (3) for the subsample of cities that enact environmental regulations, whereas they are not significant in columns (2) and (4) for the subsample of cities that do not. The results indicate that the enactment of environmental regulations by cities can help them better conduct GSC piloting, thereby promoting enterprises' green innovation performance. The Suest test values were all significant, indicating that the impact of city GSC pilot on enterprises was significantly different among the samples of environmental regulations in different cities.

5.6 Economic consequences of GSC pilots to enhance green innovation

Referring to Wang and Wang (2021), we developed a model to examine the economic impacts of implementing green innovation initiatives through city GSC pilots.

$$ESG_{i,t}/TQ_{i,t} = \beta_0 + \beta_1(\gamma GI) + \sum Controls + \sum Year + \sum Industry + \sum City \tag{4}$$

The explanatory variable for environmental, social, governance (ESG) indicates corporate ESG performance and is measured using the ESG rating scores of listed companies and the China Securities ESG rating. The explanatory variable *TQ* denotes corporate financial performance, measured using Tobin's Q. The explanatory variable GI, which indicates green innovation triggered by the city GSC pilot, is equal to ($_1$Treat × Post + $_2$Post) in Model (1), and GIS and CIZ are calculated separately. The control variables are consistent with those in Model (1).

The regression results for the economic consequences of green innovation enhancement by city GSC pilots are presented in Table 11. The coefficients of GIS and CIZ in columns (1) and (2) are both significantly positive, indicating that such green innovation significantly

Table 11 Economic consequences of city green supply chain pilots for enhance green innovation

Variables	(1) ESG	(2) ESG	(3) TQ	(4) TQ
GIZ	0.113** (2.04)		0.247** (2.48)	
GIS		0.065** (2.04)		0.142** (2.48)
Constant	− 2.383** (− 2.13)	− 2.383** (− 2.13)	− 0.987 (− 0.49)	− 0.987 (− 0.49)
Observations	11,608	11,608	11,731	11,731
R-squared	0.096	0.096	0.116	0.116
Control	YES	YES	YES	YES
Industry FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
City FE	YES	YES	YES	YES

t-statistics in parentheses
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

improves enterprises' ESG performance. The coefficients of GIS and CIZ in columns (3) and (4) are both significantly positive, indicating that green innovation enhanced by the city's GSC pilot also significantly contribute to enterprises' economic performance.

6 Conclusion and policy implications

6.1 Conclusion

The urban GSC pilot is a policy aimed at encouraging businesses to adopt green practices in their SCM and promote environmentally friendly and sustainable development. Since pilot work dependence was first implemented in 2018, the policy encourages enterprises to adopt environmental protection, energy saving, carbon reduction, and other measures in the supply chain process by providing policy support, guidance, and incentives to mitigate environmental hazards, enhance the efficiency of resource utilization, and foster sustainable urban growth. This study used data from Shanghai and Shenzhen A-share listed companies from 2016 to 2020 to examine the impact of urban GSC pilot projects on corporate green innovation performance.

The findings indicate that the implementation of the urban GSC pilot has a substantial positive impact on enterprises' green innovation performance, which remains valid even after conducting a range of rigorous tests to ensure its reliability. An analysis of the mechanism of action found that the urban GSC pilot mainly promoted the green innovation performance of enterprises through external urban regulatory pressure and the internal supply chain regulation pressure of supply chain members. Further research has found that the effect of the GSC pilot policies on green technological innovation was more pronounced in companies with green investors and in cities with urban environmental laws. Finally, the empirical results of this study show that green innovation triggered by urban GSC pilot policies can improve both ESG performance and economic performance of enterprises. The results provide a reliable empirical basis for other cities to implement GSC pilot policies and develop green management for the entire supply chain process.

The limitations of this study are as follows. First, this study only considers cities in China as the research object, and the research conclusion has regional limitations. Future research could expand the sample scope and combine other methods, such as questionnaire surveys and case studies, to make the results more universal. Second, owing to the complexity of the study, only green investment and urban environmental regulations were included as boundary conditions. Future studies should explore the influence mechanisms of other factors on the relationship between urban GSC pilots and enterprise green innovation to expand the scope of this study. Third, because of difficulties in data acquisition, this study only selected the number of green patent applications to measure green innovation performance. Future studies could attempt to measure green innovation from investments in green technology and green productivity (such as energy consumption, pollutant emissions, and resource utilization efficiency) to further improve the conclusions of this study.

6.2 Policy implications

Drawing from the findings of the aforementioned research combined with the macro- and micro-economic situation in recent years, this study attempts to provide the following policy recommendations:

First, the implementation of urban GSC pilot policies should be deepened, the scope of urban pilots expanded, and their driving roles improved. It is imperative to enhance the guidance provided to key corporations, enabling them to effectively lead the green innovation efforts of supply chain-associated enterprises. This will foster a novel framework for collaborative green innovation among small and medium-sized businesses within a supply chain driven by larger corporations. However, to encourage a greater number of businesses to prioritize green innovation within their supply chains, it is essential for the government to enhance policy promotion efforts, enterprise awareness and engagement in GSC management, and implementation of a range of policy incentives, such as financial subsidies and tax incentives, to mobilize enterprises' enthusiasm to participate. They should establish and improve green procurement, credit, taxes, carbon emissions trading, and other incentive mechanisms in the market, forming an institutional environment conducive to enterprises creating GSC.

Second, it should focus on national governance, strengthen supervision, and improve relevant laws and regulations. The urban GSC pilot policy can further improve enterprises' green innovation performance by strengthening urban supervision and supply chain regulation pressure. The government should formulate detailed management norms and standards to clarify enterprises' responsibilities and obligations for implementing GSC. At the same time, supervision should be strengthened, enterprises that do not comply with regulations should be punished, and the implementation of the policy should be ensured. An effective regulatory mechanism should be established to supervise and manage the implementation of GSC management by enterprises through regular inspections and random checks. Additionally, it is necessary to encourage the establishment of internal norms and self-discipline mechanisms among supply chain members, promote cooperation and mutual supervision among members, and create a sustainable industry atmosphere. The effectiveness of communication and collaboration among members of the supply chains should be strengthened, the sharing of information and exchange of experiences facilitated, and the adoption of GSC management collectively driven. Third, strengthening the construction of the urban GSC system and promoting urban GCS pilots will play a greater role in governance. Green investors' participation in GSC management practices has a significantly positive impact on enterprises' green innovation performance. The government should provide incentive measures (e.g., investment guarantees and preferential policies), strengthen communication and cooperation with green investors, and create a favorable investment environment for green investors. Simultaneously, a monitoring and evaluation mechanism should be established to evaluate and provide feedback on the effect of policy implementation; objectively evaluate the effect of policy implementation; adjust and optimize the policy according to the evaluation results; dynamically adjust and improve the policy; strengthen communication and collaboration with all relevant parties; establish information sharing and exchange mechanisms; and collaborate to advance the execution and growth of pilot policies for urban GSCs.

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Data availability Data will be made available on request.

Declarations

Conflict of interest No conflict of interest exits in the submission of this manuscript. The authors have no financial or proprietary interests in any material discussed in this article.

Appendix 1. City environmental attention dictionary

Environmental protection category: environmental protection, environmental protection, environment, pollution prevention, pollution control, pollution management, pollution control, greening, green, green development, low-carbon, emission reduction, ecology, sewage treatment, sewage treatment environmental impact assessment, environmental protection inspectors, household waste without harm, environmental quality, air quality.

Environmental pollution category: pollution, emissions, chemical oxygen demand, sulfur dioxide, carbon dioxide, particulate matter, PM2.5, ammonia, nitrogen oxides, air pollution, pollutants, dust, dust reduction, waste, garbage, emissions, air, chemical oxygen demand, sulfur dioxide, carbon dioxide, PM10, haze, greenhouse gases.

Energy consumption category: water consumption, energy consumption, consumption, resources, conservation, intensive, energy, new energy, clean energy, coal to electricity, coal to gas, centralized heating, reuse, recycling, renewable.

Synergistic development and environmental governance: key words-Beijing-Tianjin-Hebei, environmental synergy, synergistic development, synergistic governance, sectoral cooperation, public participation, junction areas, sharing, transfer, joint prevention, joint control, joint governance, regional coordinated development, integrated watershed management, regional cooperation, complementary advantages, win–win cooperation, joint promotion, protection collaboration, synergistic pollution control, sustainable.

Other categories: blue sky, blue water, clean land, green land, forest, river chief, river chief system, lake chief, lake chief system, stay green, stay white, livable, tree planting, afforestation, green water and green mountain, blue sky and white clouds, ecological barrier, water conservation, soil and water conservation, development, soil, returning farmland to forest, natural forest.

Appendix 2. Green investor dictionary

Environmental protection, ecology, green, new energy development, clean energy, low carbon, sustainable, energy saving, green development, clean energy, recycling, renewable.

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