Economic Change and Restructuring (2023) 56:3187–3215
https://doi.org/10.1007/s10644-023-09521-9

Does green credit policy promote corporate green innovation? Evidence from China

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Received: 3 January 2023 / Accepted: 8 May 2023 / Published online: 19 May 2023

Abstract
Green innovation is an important strategy for companies to achieve sustainable development goals. In addition to helping companies create a green image and improve their competitive advantage, green innovation can reduce pollution and improve the ecological and social environment, with positive external effects. The green credit policy (GCP) is an addition to traditional environmental regulations. Taking the 2012 Green Credit Guidelines as a quasi-natural experiment, this study finds that GCP significantly reduces the quantity and quality of green innovation in green credit-restricted firms by discouraging enterprises' debt financing. Heterogeneity analysis showed that the negative impact was concentrated mainly on non-state-owned enterprises (non-SOEs). This study recommends diversifying financing channels to ease corporate debt financing constraints. The conclusions could enrich existing research on the economic consequences of environmental regulatory policies and provide a reference for the strategic planning of green innovation development in enterprises.

Keywords Corporate green innovation · Green credit policy · Debt financing · Ownership structure · Green recovery

JEL Classification D21 · L33 · O31 · Q55

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1 Introduction

The enormous harm caused by the COVID-19 pandemic to the global economy (Cassetti et al. 2023), combined with climate change and growing public concern about environmental issues (Shang et al. 2021), has created a unique economic crisis in that environmental sustainability is as important as economic recovery. Therefore, the governing authorities worldwide have introduced economic stimulus and environmental protection programs, such as the Green New Deal (US), "Dual Carbon" goals (China), and the "Next Generation EU" strategy (Gusheva and de Gooyert 2021; Cassetti et al. 2023). Innovation in financial instruments has led to new investments in sustainable development and green economic recovery. Green financial instruments, such as green bonds, have been widely used worldwide, and environmental finance has been considered an effective way to prevent environmental degradation (Deschryver and de Mariz 2020; Cheng et al. 2022). As one of the leading developing countries in the world, China attaches great importance to the role of green finance. Green finance enables the allocation of financial resources. In addition to supplementing traditional environmental supervision tools, it is important to explore the promotion of market-driven environmental governance development in China. Since 2007, the Chinese government has repeatedly proposed controlling credit to polluting firms in its policy documents on credit risk.

Green innovation can reconcile economic growth with environmental protection, potentially achieving a 'win−win' situation for economic efficiency and environmental protection. Green innovation has the negative externalities of environmental pollution and cannot be driven by companies alone (Shen et al. 2020). In many cases, the government uses environmental regulation policies to assist or regulate companies to achieve ecological development (Hu et al. 2021b). However, there are disputes regarding the effects of environmental regulatory policies. Based on a long-term dynamic perspective, Porter and Linde (1995) believed that environmental regulation would stimulate the green innovation of firms to enhance competitiveness, with the aim of offsetting the additional costs of environmental regulation and forming the compensation effect of innovation. In addition to being an effective way to solve the externalities of environmental pollution, environmental regulations are also major contributors to technological innovation (Jaffe and Palmer 1997; Rubashkina et al. 2015; Liu and Li 2022). However, some scholars believe that environmental laws and regulations cause an additional increase in business costs and inhibit technological innovation (Shi and Xu 2018). Some studies argue that different environmental regulations have different impacts on green innovation activities and efficiency. Command-based environmental tools (laws, legislation and regulation rules) are conducive to innovation in corporate end governance, whereas market-based environmental tools (carbon tax and Carbon Emission Trading Scheme) support green processes and innovation in end governance (Li et al. 2017; Borsatto and Bazani 2021).

The impact of China's GCP on the economy and environment depends on the responses of its financial institutions and enterprises. The GCP has improved the difficulty of obtaining financial resources in practice, realized the control of credit quotas, and promoted the redistribution of resources among enterprises of different natures. According to Porter's hypothesis, highly polluting firms have a stronger motivation to engage in green innovation to reduce the negative impact of financial regulatory policies on firms. However, in practice, firms may face more stringent credit constraints. Can firms undertake innovative activities that rely on financial support when faced with external financing difficulties? Can the GCP help heavily polluting enterprises achieve green development? Several studies have discussed the impact of GCP on corporate green innovation (Hu et al. 2021a; Liu et al. 2021), but the findings remain controversial (Borsatto and Bazani 2021). Moreover, it focuses primarily on the impact of GCP on the number of green patents of enterprises, and less research has focused on the quality of green patents of enterprises (Wang et al. 2022a). GCP impacts enterprise financing (He and Liu 2023). Some studies suggest that financing constraints can affect firms' innovative activities (Cornaggia et al. 2015). However, the evaluation of policy effects based on financing constraints is relatively fragmented. This study investigates the relationship between GCP and corporate green innovation as well as the intermediary role of financing constraints. A difference-in-differences model was adopted to examine the impact of GCP on corporate green innovation, and the study found that GCP significantly reduced the quantity and quality of green innovation in green credit-restricted firms. The mechanism test showed that GCP negatively affected green innovation behavior by discouraging enterprises' debt financing. The negative impact is mainly concentrated in non-SOEs. Our conclusions provide evidence and policy recommendations for developing countries to promote green finance and green development.

Specifically, this study contributes to the literature in three ways. First, there is no consensus regarding the relationship between environmental regulations and corporate innovation. This study focuses on the GCP, a new environmental regulation tool, and uses the difference-in-differences (DID) model to examine the impact of the GCP on the quantity and quality of corporate green innovations. The results of this study show that the GCP has not achieved the expected policy effect. The conclusions provide empirical evidence from developing countries to enrich the environmental regulation and green innovation of enterprises. Second, this study found that GCP adversely affects corporate green innovation by increasing financing constraints. This conclusion provides evidence of how GCP restricts corporate green innovation. Third, differences in the impact of green credit constraints on firms' innovation activities are discussed from the perspectives of ownership, scale, and region, which enrich the analysis of heterogeneity. It was found that differences in capital attributes, enterprise scale, and regional financial development levels are also important factors affecting the innovation effect of green credit policies. The results show that the GCP needs further adjustment to advance green economic recovery.

The remainder of this paper is organized as follows. Section 2 introduces the relevant literature. Section 3 proposes the research background and hypotheses. Section 4 introduces the variables, data, and models. Section 5 presents an empirical analysis. Section 6 presents conclusions and policy recommendations.

2 Literature review

Green recovery has become more popular since the COVID-19 pandemic and refers to economic activities that can achieve economic recovery and have a positive impact on the environment (Hepburn et al. 2020; Gusheva and de Gooyert 2021). The impact of technological advancements on pollution levels and economic development has been recognized for some time. In the long term, green technological innovation will have a decisive impact on green growth (Wang et al. 2022c). In an unfavorable global environment, it is imperative to encourage and support collaborative green innovation.

Green innovation emphasizes the importance of resource conservation and environmental friendliness. It is the general term for green improvement or the creation of technologies, processes, and products (Schiederig et al. 2012). Green innovation is a branch of responsible innovation that has the dual externalities of sustainability and innovation and can easily lead to market failure, especially in developing countries. Furthermore, green technological innovation has a more important position, defined as including a range of new or improved processes, technologies, systems and products that can avoid or reduce environmental harm (Arundel and Kemp 2009). An effective retrieval tool is provided by the World Intellectual Property Organization (WIPO) and can be used to identify patent classification numbers related to environmentally friendly technologies. Compared with general innovation, green technology innovation has a double externality problem (Xie and Teo 2022). Oltra and Saint Jean (2009) and Horbach et al. (2012) believed that green technological innovation originated from the interaction between market demand, technology, and environmental policies. Existing research on its influencing factors is mainly conducted from the perspectives of the market, technology, and the internal and external environments of enterprises. Market demand can motivate enterprises to increase innovation investment, thereby promoting the green innovation of enterprises (Shao et al. 2022). Krueger et al. (Krueger et al. 2020) believed that institutional investors had an important impact on the green development of enterprises and that whether they considered climate risk in their investment decisions was a very important issue. Amore et al. (2019) studied the impact of CEOs' educational background on enterprise innovation. However, political capital in enterprises has a significant negative effect on green products and the innovation performance of enterprises (Lin et al. 2014). Stakeholder pressure, especially the internal supervision of enterprises, has a significant positive incentive to reduce the externalities of enterprises and pollution emissions (Shive and Forster 2020).

Some studies have focused on the impact of environmental regulations, which can be broadly categorized into three viewpoints. Some scholars believe that environmental regulations positively impact green corporate innovation. Command-and-control policies are targeted more at energy conservation and emission reduction technology innovation, especially in industries with a high degree of nationalization (Wang and Qi 2016). Xie et al. (2017) studied the impact of different regulatory tools on enterprise productivity. Their research conclusions further supported the Porter hypothesis, that is, reasonable regulatory tools will improve enterprise competitiveness. Turken et al. (2020) and Zhou et al. (2022a) believed that environmental regulations “force” the development of green technology by enterprises. Zhong and Peng (2022) claimed that China’s new environmental protection law has a positive impact on corporate green innovation. However, some studies have shown that environmental regulation increases the cost burden and adversely affects green corporate innovation. In a study by Weber and Neuhoff (2010), different regulations on carbon emission trading were discussed, and it was believed that improving innovation efficiency could provide incentives for private R&D investment. Carrión-Flores et al. (2013) studied the negative impact of voluntary government-supported pollution reduction plans on long-term environmental performance. Li et al. (2019) found that command-and-control regulations, such as pollutant emission standards, adversely affect environmental technology innovation. Fu and Jian (2021) found that the impact of China’s environmental regulations on corporate innovation is insignificant. Some studies also suggest that there are uncertainties regarding the impact of environmental regulations on green innovation. Borsatto and Amui (2019) pointed out that the relationship between environmental regulations and green innovation is inconsistent. Ouyang et al. (2020) found that there is a U-shaped relationship between environmental regulations and technological innovation in industrial sectors.

Currently, green credit and green bonds are the most widely used green financial instruments. They complement traditional environmental regulations (Zhang et al. 2021a). The microeconomic impact of GCP is mainly concentrated on the impact of both tools. Studies considering green bonds explore green bond pricing and its impact on firm value (Zerbib 2019; Tang and Zhang 2020; Flammer 2021; Bhutta et al. 2022; Jiang et al. 2022). At present, there are different opinions on the effectiveness of GCP (Zhang et al. 2022a). Research on GCP mainly involves its impact on enterprises’ investment and financing decisions, corporate green technological innovation, and industrial green total factor productivity. Xu and Li (2020) argued that the GCP asymmetrically affects corporate debt financing. The Green Credit Guidelines clarify the standards and principles of GCP for financial institutions. Banking and other financial institutions are required to consider factors such as conservation, environmental protection, promotion of national health, and maintenance of biodiversity as important conditions for credit decisions and to effectively identify and control environmental and social risks in credit business activities to maximize the reversal of environmental degradation (Zhou et al. 2022b). In addition, many studies have considered the relationship between green finance and enterprise innovation. After studying the relationship between GCP, property rights, and debt financing, Liu et al. (2019) found a significant negative relationship between China’s GCP and the debt financing of highly polluting state-owned enterprises (SOEs). Liu et al. (2015) argued that GCP has no long-term impact on firm output. Han et al. (2022) found that China’s Green Finance Reform and Innovation Pilot Policy has a significant role in promoting enterprises’ green innovation. According to Qi (2021), the GCP positively affects the investment efficiency of highly polluting firms in areas with better financial ecology. Hao et al. (2020) argued that the GCP has a more positive impact on heavy polluters in regions with higher marketisation levels. Cao et al. (2021) argued that the dynamic effect of GCP is a diminishing disincentive and that it can facilitate the green transformation of heavily polluting enterprises that are actively engaged in social responsibility. Wang et al. (2022b) found that officials' promotional pressure has a negative moderating effect on the positive effect of green credit guidelines in China.

Most previous studies have focused only on the quantity of green innovation and ignored the quality of green innovation when discussing the relationship between the GCP and corporate green innovation, resulting in numerous low-quality and low-cost innovations (Wang et al. 2022a). This study focuses on the impact of the GCP on the quantity and quality of green corporate innovation. Financing remains one of the biggest challenges to advancing green recovery and sustainable development (Ge and Zhu 2022). This study further analyses the channels through which the GCP impacts green corporate innovation. This study considers the heterogeneity of different property rights, enterprise sizes, and regions to provide policy suggestions for improving green finance and achieving green recovery.

3 Background and research hypotheses

3.1 Policy background

In 2007, the Ministry of Ecology and Environment and the CBRC jointly issued Opinions on Implementing Environmental Protection Policies and Regulations to Prevent Credit Risks, indicating that the government has started using green credit as an essential environmental protection tool for energy conservation and emissions reduction. Environmental performance evaluations are also essential for bank credit (Zhang et al. 2022b). In 2012, the China Banking Regulatory Commission issued Green Credit Guidance, which provides detailed regulations on organizational management, implementation processes, supervision, and inspection. This release indicates that the green credit policy (GCP) was formally implemented in 2012. To the best of our knowledge, this study is the first to examine green-credit operations in China. The GCP requires the establishment of a threshold for environmental access in the area of financial credit, the cutting off of sources of financing for the disorderly development and blind expansion of enterprises with high energy consumption and pollution, and the strengthening of credit support for the circular economy, environmental protection, and energy-saving and emissions-reduction technology adaptation projects (Wang et al. 2022a). Obtaining debt financing from financial institutions is the most important financing channel for enterprises in China (Li et al. 2022). Any economic decision-making and innovation behavior of an enterprise cannot lack sustainable and stable funds. There is no doubt that the implementation of GCP has an impact on the green innovation behavior of enterprises.

3.2 Theoretical background

From a macro perspective, according to signal theory, the GCP can transmit green development signals through the credit channel (Cheng et al. 2022). The GCP mobilizes capital accumulation by reallocating financial resources, such as credit inclinations and differentiated interest rates, and uses a capital scale-oriented mechanism to provide capital elements for green economic recovery and promote green investment (Li et al. 2023). From a micro-perspective, the new growth theory emphasizes the importance of knowledge. Economic growth comes from change in knowledge returns, and technological innovation has always been the core of theory (Romer 1990). Enterprises need financial support from the financial market to support innovation activities, while enterprises in developing countries use debt financing from formal banks (Ayyagari et al. 2011). Factors on the supply side of financial markets may impact corporate financing decisions. Moshirian et al. (2021) conducted a sample study on 20 countries that have experienced capital market opening. They found that capital market opening is conducive to improving national innovation levels, especially in innovative industries. According to Nanda and Nicholas (2014), during the Great Depression, the banking crisis severely hampered improvements in the number and quality of corporate patents, suggesting an influence on the credit market and innovation of companies. Financing constraints on firms' innovation weaken as banks' competitive landscape strengthens (Chong et al. 2013), and the intensity of innovation gradually increases (Cornaggia et al. 2015). However, some scholars believe that banks, as creditors, would avoid risks more for the purpose of profit. Such inherent prejudice when banks make credit decisions hinders enterprises' innovation activities (Morck and Nakamura 1999). GCP has a credit constraint effect on corporate green innovation. GCP may reduce the possibility and scale of credit resources for heavily polluting enterprises, thereby affecting corporate innovation and R&D investment (Lu et al. 2020).

3.3 Hypothesis development

The main purpose of the GCP is to strengthen the support for green credit for green development. In the Green Credit Guidelines, financial institutions such as the banking sector are required to promote green credit from a strategic perspective and implement incentive and restraint measures. Institutions must fully consider the environmental and social risks involved in credit operations and refuse to extend credit to enterprises or projects that do not meet environmental and social standards. Bank credit is an important source of funding for corporate R&D investment activities. The traditional financial market is concerned with the profitability of investment projects and is likely to ignore the resource and environmental factors in investment projects. The GCP has led to a shift in investment direction, directing investments from green credit-restricted firms to environmental protection areas. Factors on the supply side of financial markets may impact corporate financing decisions. Banks must control credit thresholds and consider environmental status as an important criterion for determining whether to lend, which leads to an increase in financing costs for green credit-restricted firms and a significant reduction in debt financing led by bank loans.

The effect of the GCP is also influenced by firms' responses. In the long run, the government has also made many efforts in green infrastructure construction to support enterprise innovation, such as China's smart city construction and construction of green financial information platforms, to provide more production factors for enterprise green innovation. In the short term, the GCP can lead to the flow of funds toward sustainable development and environmental governance objectives. On the one hand, corporate innovation is naturally characterized by a high failure rate, and the financing constraints inherent in corporate innovation activities lead to more stringent financing costs, loan conditions, and credit collateral requirements for companies with innovation activities. This is especially true for green credit-restricted enterprises, which have weaker competitive advantages than non-polluting industries. In addition, the type of financing affects the speed and choice of direction of innovation activities (Mazzucato and Semieniuk 2017). Since corporate innovation activities generally last for a long period of time, banks tend to grant long-term loans to firms in clean sectors when GCP is implemented, and long-term debt financing for green credit-restricted firms may decline more. However, the response of green credit-restricted companies remains uncertain. The question of whether they will have the Porter effect of actively performing green technological innovation when credit constraints or reducing green technological innovations due to rising funding costs requires further discussion. On the other hand, banks take the initiative to raise their lending threshold to improve their own green ratings after the GCP. Although green credit-restricted enterprises may be able to transform through green innovation activities, compared to non-green product patents, green product patents require higher technology and more investment, making it difficult for green credit-restricted enterprises to transform in the short term. Hence, the following hypothesis is proposed:

Hypothesis 1 After the implementation of the GCP, green innovation by green credit-restricted enterprises will decline compared to non-green credit-restricted enterprises.

Innovation activities need not only the amount of capital but also the long-term stable investment of capital. The main effect of GCP on the innovative activity of green credit-restricted enterprises is mainly realized through the limitation of financing capacity. The mechanism analysis framework is constructed (as shown in Fig. 1). Due to the strong credit constraints imposed by financial institutions, enterprises will be unable to carry out green innovation due to a lack of funds despite their demand for green innovation. As a positive incentive, banks have more motivation to lend to non-restricted enterprises to encourage development, which also produces a capital crowding out effect on heavily polluting enterprises. Financial

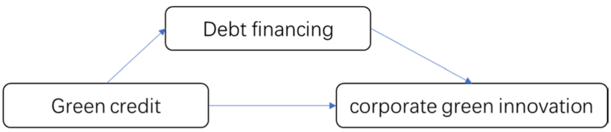

Fig. 1 The impact mechanism of the GCP on corporate green innovation

institutions need to comply with government regulatory constraints in their lending business, and the costs of violating the green credit guidelines are far greater than the benefits of financing companies in heavily polluting industries. Therefore, banks, as the main source of capital for the industry, will take a prudent attitude toward the financing needs of heavily polluting industries. In particular, long-term borrowing needs are more likely to be considered by regulators, which brings challenges to the long-term stable financing needs of credit-restricted firms. This illustrates the problem with the GCP, which, although it regulates polluting industries, is more often used as a form of financing squeeze punishment for credit-restricted firms than as a reward for solving technological bottlenecks. Therefore, the following hypothesis is proposed:

Hypothesis 2 The GCP discourages green innovation among green credit-restricted enterprises by reducing long-term and short-term debt financing.

The marginal cost of ownership varies across firms, and firms need to weigh the extent to which the cost of financing corporate debt rises over the course of their operations. SOEs have an implicit government guarantee, and their debt is less likely to default. Coupled with the longer survival of SOEs and the existence of stable banking relationships with state-owned banks, there are major differences between companies with distinct ownership in terms of access to bank loans. Brandt and Li (2003) also argue that all other things being equal, private enterprises are less likely to obtain loans and receive smaller amounts of loans but face more stringent loan conditions.

While the government has an incentive to intervene in banks' lending decisions, the implementation of the GCP has also created some constraints on banks' performance assessment of green lending. Banks and other financial institutions face a trade-off when making lending decisions; therefore, the financing constraints of state-owned green credit-restricted firms also increase, and the green innovation activities undertaken by SOEs may be affected. However, private green credit-restricted firms with narrow access to debt financing may be more inhibited in their green innovation activities than SOEs. The following hypothesis is developed:

Hypothesis 3 The disincentive to green innovation activities of non-state green credit-restricted enterprises was more pronounced after the implementation of the GCP.

4 Data and methodology

4.1 Data source

The initial sample of this study was based on Chinese A-share listed companies during the period 2007–2019 to investigate the relationship between GCP and corporate green innovation—the year 2008 was crucial for the development of GCP in China.

The Chinese government has issued a list to verify the environmental protection situation of the industries mentioned and has identified heavily polluting enterprises and environmentally friendly enterprises. This policy is a milestone in the development of energy conservation and emissions reduction. This study combined the Environmental Verification Industry Management List of Listed Companies with the previously issued Industrial Classification Guidelines for Listed Companies to identify the industries affected by green credit.

The data sources for this study include two main components: (1) Data on corporate green innovation. In 2010, the World Intellectual Property Organization (WIPO) launched an online tool, the "International Patent Classification Green List," that helps obtain information on patents for environmental technologies. This list can better identify green technology patents for different countries and enterprises when formulating policies. Green patents can be divided into seven categories: transportation, waste management, energy conservation, alternative energy production, administration or design, agriculture or forestry, and nuclear power generation.

To clarify the level of green innovation, the China Research Data Service Platform (CNRDS) database was used. CNRDS can distinguish, sort, and screen the data in the patents of the State Intellectual Property Office of China and search according to the definition of the green patent standard of the World Intellectual Property Organization and then determine the number of green patent applications and green patents obtained by companies. (2) Data on other company characteristics. The influence of a company's financial indicators and governance structure on the green innovation level also needs to be considered. The main financial data were obtained from the Wind database, whereas other financial data, shareholder data, and data on actual controllers were obtained from CSMAR.

Additional measures were taken to ensure the complete disclosure of data by enterprises. (1) This paper excluded enterprises with abnormal asset-liability ratios whose value is lower than 0 or higher than 1. (2) Newly listed firms after 2007 were excluded from the analysis. (3) Differences in accounting standards make it impossible to compare firms' relevant financial indicators. Our analysis excluded firms listed in the financial industry. (4) Companies referred to as special treatment and special transfer companies were omitted because they have abnormal financial performance. (5) Companies that became insolvent were excluded, and (6) this paper winsorized the continuous variables at the 1% level.

4.2 Variable selection

4.2.1 Dependent variables

Defining measurement standards for innovation has always been the focus of research. There are two feasible methods to measure the importance of enterprise innovation: (1) through the capital investment of enterprise innovation and (2) through the innovation effect through the product output of an enterprise. With the continuous improvement in patent data quality, the information content contained in patent data is increasing, which is more specific and reliable as an indicator of the enterprise innovation level. Dang and Motohashi (2015) pointed out that the number of patents is a better indicator of a firm's level of innovation. Different types of enterprise patent data can show different information. Basically, corporate patent data can be divided into two types of data: the number of patent applications and patents granted. Given the complexity and length of the process from application to granting the patent and the impact patented technology can have on the company during the application process, this study believes patent application data are consistent with our research, representing it more. However, the number of patents does not fully reflect the level of innovation, and patent quality is more important in practical research. Previous literature mainly focuses on the impact of environmental regulation on the number of green patents and attempts to describe the level of innovation in terms of the number, ignoring the analysis of the quality.

The variable Y_{it} includes three dependent variables: green innovation quality (*Total*), green innovation quality (*Inva*), and comparative variables of enterprise green innovation quantity (*Uma*). Specifically, *Total* is the sum of green invention patent applications and green utility model patent applications. The number of green invention patent applications measures the quality of green innovation (variable *Inva*). This paper used the number of patent applications for the green utility model (variable *Uma*) as a comparative index of *Inva*. The natural logarithm is taken as the number of indicators above plus one to obtain *LnTotal*, *LnInva*, and *LnUma*.

4.2.2 Independent variable

The core independent variable in this study is the interaction term $Treat_i \times Policy_t$, where both $Policy_t$ and $Treat_i$ are dummy variables. $Policy_t$ is the GCP implementation dummy variable, and Treat is the green credit restriction industry variable. By observing the coefficient of $Treat_i \times Policy_t$, this paper can directly identify and quantify the impact of GCP on corporate green innovation.

4.2.3 Control variables

In reference to the existing literature (Liu et al. 2019; Hao et al. 2020; Han et al. 2022; Zhang et al. 2022a), this paper controlled for the following variables. That is, (1) enterprise assets scale, which is indicated by the natural logarithm of the enterprises' total assets (*LnSize*). Large enterprises are conducive to enterprise innovation in terms of cash flow, human capital skills, and innovation cost distribution, while small- and medium-sized enterprises (SMEs) have more advantages in adjusting research plans and implementing innovation flexibly (Rogers 2004); (2) Cash flow of enterprise, measured by the ratio of cash holdings to total assets (*Cash*); and (3) the ratio of liquid assets to total assets (*Flow*). Cash can reasonably measure enterprises' profitability. SMEs with rich cash flow are usually more inclined to invest in R&D activities (Zhao et al. 2022); (4) debt-paying ability, indicated by the logarithm of asset-liability ratio (*LnDebt*); (5) proportion of fixed assets, measured by the proportion of fixed assets in total assets (*Fasset*); and (6) R&D investment, measured by the logarithm of companies' R&D expenditure (*LnRD*). Generally, companies with highly liquid assets tend to invest more in enterprise R&D and produce more innovative results (Pham et al. 2018); (7) The number of employees, which is the logarithm of the number of employees in the business (*LnEmployee*); (8) *Inst*, which is indicated by the shareholding ratio of institutional investors; (9) *Largest*, indicated by the shareholding ratio of the largest shareholder. If Largest is very high, it indicates that the decision-making ability is too centralized, which usually reduces the willingness to innovate because of private interests of control (Zhao et al. 2021). (10) Age. The logarithm of the number of years since its initial listing in the Chinese stock market (*LnAge*). A company's age represents its experience. With the accumulation of enterprise experience, the quality of enterprise innovation changes over time (Balasubramanian and Lee 2008); (11) *Tonbin Q*, *i*ndicated by the ratio of enterprise market value to capital replacement cost; (12) Company growth, indicated by the growth rate of operating income (*Grow*). The specific definition of variables is shown in Table 1.

4.2.4 Mediating variables

The mediating variables include the following: (1) *Floan*, indicated by the ratio of the sum of a company's long-term and short-term borrowings to its total assets; (2) *Flloan*, indicated by the ratio of long-term borrowings to total assets of an enterprise.

4.3 Model construction

Difference-in-difference (DID) is used in public policy evaluation. The implementation of a public policy has affected some groups in society in a non-random way, and the effect of the policy can be understood by comparing the treatment group affected by the policy with the control group not affected by the policy. The DID model uses the dual differences in cross-sectional and time-series brought about by an exogenous public policy to identify the "treatment effect" of public policy. The following model, based on the DID model, investigates whether GCP has a positive effect on the behavior of companies and whether it can promote corporate green innovation.

$$\text{Model 1}: \; Y_{it} = \alpha_0 + \beta_1 Policy_t + \beta_2 Treat_i \times Policy_t + \beta_3 Treat_i + \gamma X_{it} + v_t + \delta_i + \varepsilon_{it}$$

Y_{it} represents a company's level of green innovation. $Policy_t$ is a dummy variable, with a value of 1 for post-implementation (2012 and later) and 0 for pre-implementation (before 2012). $Treat_i$ indicates whether enterprise i belongs to a green credit-restricted industry. The codes for green credit-restricted industries in this study are summarized in Table 1. If the industry to which an enterprise belongs falls within the classification in Table 2, it is an enterprise in a green credit-restricted industry and takes the value of 1; otherwise, it takes the value 0. X_{it} represents a series of control variables. v_t represents the year fixed effect, and δ_i denotes the industry fixed effect. Additionally, ε_{it} is a random error term. The setting of the interaction term is significant in the model. The coefficient of the interaction term provides a better understanding of the impact of GCP on corporate green innovation. If β_2 is significantly greater than 0, it indicates that the policy significantly facilitates green

Table 1 Variable definitions

	Variable name	Description	Source
Dependent variables	Green innovation quality *(LnTotal)*	The logarithm of the total number of green patent applications plus one	CNRDS
	Green innovation quality *(LnInva)*	The logarithm of the total number of green invention patent applications plus one	CNRDS
	Green innovation quality *(LnUma)*	The logarithm of the total number of green utility model applications plus one	CNRDS
Independent variable	Green credit policy (*Treat* × *Policy*)	*Policy* is the GCP implementation dummy variable, and *Treat* is the green credit-restriction industry variable. If the sample is in 2012 or later, *Policy* = 1, otherwise *Policy* = 0; if it is a green credit-restricted enterprise, *Treat* = 1, otherwise *Treat* = 0	
Control variables	Enterprise total assets (*LnSize*)	The natural logarithm of the company's total assets	CSMAR; Wind
	TobinQ (*TobinQ*)	The ratio of enterprise market value to capital replacement cost	CSMAR; Wind
	Number of employees (*LnEmployee*)	The natural logarithm of the company's total employees	CSMAR; Wind
	Age of the enterprise (*LnAge*)	The natural logarithm of the company's year of existence	CSMAR; Wind
	Debt-paying ability (*LnDebt*)	The natural logarithm of asset-liability ratio	CSMAR; Wind
	Cash flow of enterprise (*Cash*)	The ratio of cash holdings to total assets	CSMAR; Wind
	Proportion of fixed assets (*Fasset*)	The proportion of fixed assets in total assets	CSMAR; Wind
	R&D investment (*LnRD*)	The logarithm of companies' R&D expenditure	CSMAR; Wind
	Institutional investors (*Inst*)	The shareholding ratio of institutional investors	CSMAR; Wind
	The largest shareholder (*Largest*)	The shareholding ratio of the largest shareholder	CSMAR; Wind
	Company growth (*Grow*)	The growth rate of operating income	CSMAR; Wind
	Firm-level liquidity (*Flow*)	The ratio of liquid assets to total assets	CSMAR; Wind

Table 2 Industry code and label of the sample company

Green credit-restricted industries	Industrial classification for national economic activities (code)
Thermal power generation	Production and distribution of electric and heat power (D44)
Steel smelting	Ferrous metal smelting and rolling processing industry (C31)
Cement manufacturing	Non-metallic mineral products industry (C30)
Coal mining	Mining and washing of coal (B06)
Metallurgy	Non-ferrous metal smelting and rolling processing industry (C32)
	Metal products industry (C33)
Construction materials manufacturing	Non-metallic mineral products industry (C30)
Mining industry	Ferrous metal mining and processing (B08)
	Non-ferrous metal mining and selection (B09)
Chemical products manufacturing	Chemical raw material and product manufacture (C26)
	Rubber and plastic products industry (C29)
Petrochemical	Processing and coking of petroleum and nuclear fuel (C25)
Medicine manufacturing	Medicine manufacture (C27)
Light industry	Food processing of agricultural products (C13)
	Wood processing and wood, bamboo, rattan, palm and grass products industry (C20)
	Food manufacturing (C14)
	Liquor, beverage and refined tea manufacturing (C15)
	Paper and paper product manufacture (C22)
Spinning and weaving	Textile manufacture (C17) Chemical fiber manufacturing (C28)

innovation in green credit-constrained industries, and if β_2 is significantly less than 0, it indicates no significant facilitation effect. To eliminate differences over time and across individuals, this study used an econometric model to control for the two-way fixed effect of regression analysis.

Next, based on the benchmark analysis, this study further investigated the mechanism by which GCP inhibited the green innovation of green credit-restricted enterprises and focused on the analysis of the mechanism behind the formation of this phenomenon. In this study, the following mediating effect model was constructed by referring to Yang et al. (2022) and Zhang et al. (2021b) to test the mediating effect.

$$\text{Model 2}: M_{it} = \beta_0 + \alpha Treat_i \times Policy_t + \gamma X_{it} + \mu_{it} + \delta_{it} + \varepsilon_{i,t}$$

$$\text{Model 3}: Y_{it} = \beta_0 + \beta_2 Treat_i \times Policy_t + \beta_4 M_{it} + \gamma X_{it} + \mu_{it} + \delta_{it} + \varepsilon_{i,t}$$

The variable M_{it} indicates a firm's financing constraints. This study further examined the specific mechanism through which green credit influences corporate green innovation. Although the GCP has a universal impact on the financing constraints of enterprise innovation, it was found that the impact is not neutral in long-term and short-term financing constraint analyses. To this end, this study added long-term bank loans as a constraint to the model to measure loan maturity. Following Cao et al. (2021), the sum of long-term and short-term borrowings was used as a measure of total assets, denoted as *Floan*, given that green patent innovation is a long-cycle behavior and firms may prefer to use long-term bank loans for innovation activities. Long-term borrowings as a proportion of total assets are also used to measure the long-term loans available to firms, denoted as *Flloan*. For comparison with previous results, the other variables in the model in this section are consistent with those in the previous section. Model (2) was introduced to measure the impact of GCP on financing constraints. Before and after the coefficient of the outer product term, Model (3) also changed significantly from Model (1).

5 Results and discussion

5.1 Regression results

Table 3 presents the descriptive statistics, which show the basic characteristics of the sample data. The three main variables that measure corporations are *LnTotal, LnInva*, and *LnUma*. *LnTota*l has a mean value of 0.605 and a maximum value of 7.592. The average and maximum values of *LnInva* and *LnUma* are 0.792, 8.285, 0.555, and 6.310, respectively. The statistical results clearly show significant differences between the enterprises' innovation levels.

Based on Model 1, Table 4 reports the regression results of GCP on firms' green innovation. Columns (1) and (2) report the regression results for total green innovation; Columns (3) and (4) for green utility model patents; and Columns (5) and (6) for green invention patents.

Table 3 Descriptive statistics

Variable	N	Mean	SD	Min	Max
LnTotal	11,679	0.605	1.062	0	7.592
LnUma	11,679	0.555	0.988	0	6.310
LnInva	11,679	0.792	1.309	0	8.285
Inst	11,679	0.432	0.222	0.006	0.891
LnEmployee	11,679	7.943	1.414	2.197	13.22
Largest	11,679	0.349	0.150	0.083	0.741
LnDebt	11,679	3.799	0.518	0.369	4.598
LnAge	11,679	2.879	0.323	1.872	3.463
LnSize	11,679	22.03	3.193	2.948	26.440
LnRD	11,679	11.43	8.586	0	21.790
Grow	11,679	0.965	2.279	−0.744	18.080
Flow	11,679	0.544	0.215	0.017	1.000
Cash	11,679	0.148	0.111	−0.059	0.936
Fasset	11,679	0.235	0.177	0	0.960
Tobin Q	11,679	2.001	1.530	0.684	31.40

Table 4 Green credit policy and corporate green innovation

Variable	*LnTotal* (1)	*LnTotal* (2)	*LnUma* (3)	*LnUma* (4)	*LnInva* (5)	*LnInva* (6)
Policy × Treat	−0.121***	−0.105***	−0.006	0.011	−0.128***	−0.110***
	(0.035)	(0.031)	(0.034)	(0.029)	(0.044)	(0.038)
Policy	0.503***	0.296***	0.353***	−0.135***	0.630***	0.385***
	(0.024)	(0.051)	(0.023)	(0.044)	(0.030)	(0.062)
Treat	−0.053**	0.752***	−0.140***	0.910***	−0.062**	0.930***
	(0.023)	(0.111)	(0.022)	(0.079)	(0.029)	(0.143)
LnAge		−0.022		−0.044		−0.030
		(0.036)		(0.035)		(0.045)
LnSize		0.008***		0.007**		0.010***
		(0.003)		(0.003)		(0.004)
LnDebt		0.032*		0.059***		0.041*
		(0.018)		(0.017)		(0.023)
Grow		−0.005		−0.005		−0.006
		(0.004)		(0.004)		(0.005)
LnEmployee		0.222***		0.189***		0.269***
		(0.009)		(0.008)		(0.010)
Inst		0.003***		0.002***		0.004***
		(0.000)		(0.000)		(0.001)
Largest		−0.002***		−0.001**		−0.002***
		(0.001)		(0.001)		(0.001)
LnRD		0.015***		0.015***		0.020***
		(0.001)		(0.001)		(0.002)
Fasset		−0.601***		−0.227***		−0.731***
		(0.072)		(0.066)		(0.089)
Flow		−0.314***		−0.187***		−0.395***
		(0.058)		(0.054)		(0.072)
Cash		0.255***		0.009		0.279**
		(0.089)		(0.081)		(0.109)
Tobin Q		−0.010*		−0.012**		−0.014**
		(0.005)		(0.005)		(0.007)
Constant	0.340***	−1.968***	0.389***	−1.986***	0.453***	−2.372***
	(0.015)	(0.175)	(0.015)	(0.145)	(0.019)	(0.220)
Year FE	No	Yes	No	Yes	No	Yes
Industry FE	No	Yes	No	Yes	No	Yes
N	11,679	11,679	11,679	11,679	11,679	11,679
R^2	0.048	0.353	0.035	0.348	0.050	0.358

***, **, *Represent 1, 5 and 10%, respectively

In both Columns (1) and (2), the coefficient of $Treat_i \times Policy_t$, on which we focus, is significantly negative at the 1% level. Its coefficient becomes −0.105 with the addition of the control variables. This result shows that GCP affects the innovation output of green credit-restricted firms and limits the total green innovation output of this industry. In Columns (3) and (4), the results indicate that GCP is weakly correlated with the green new patent output of enterprises with green credit constraints. In Columns (5) and (6), the coefficient of $Treat_i \times Policy_t$ is also negative at the 1% level, indicating that GCP significantly limits the quality of the green innovation output of green credit-restricted firms. This indicates that the implementation of the policy did not encourage green credit-restricted enterprises to engage in green innovation. Thus, Hypothesis 1 is confirmed. The GCP is an important factor that influences creditors' credit decisions. The results of the model demonstrate the impact of GCP on corporate green innovation. When the policy was implemented, the ability of green credit-restricted enterprises to obtain loans from financial institutions was limited, which further affected their ability to carry out green innovation.

5.2 Reliability test

To exclude the interference of the research conclusion by other unobserved variables, this study randomly assigned the experimental group to the entire sample through random sampling for the placebo test. The operation was repeated 1000

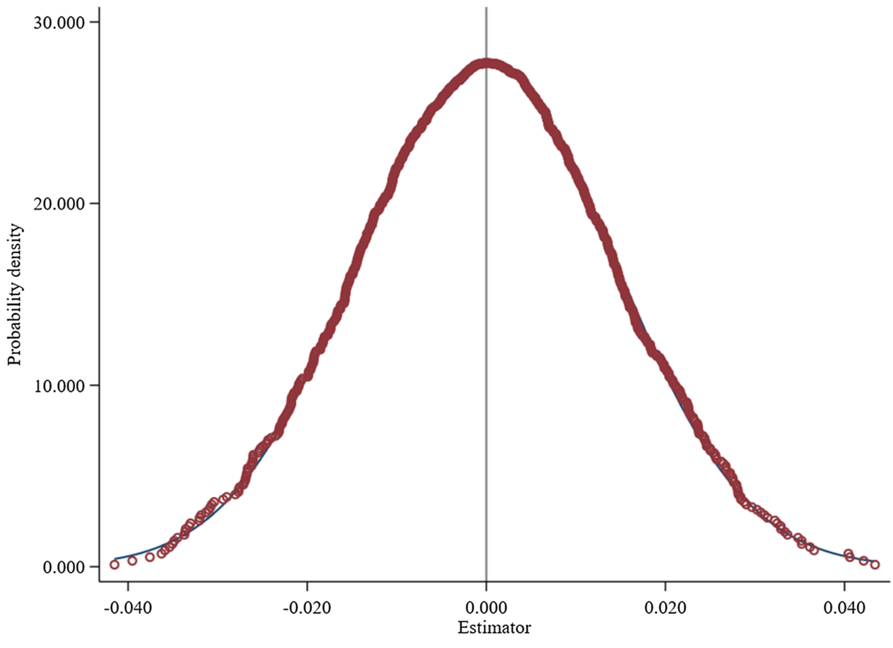

Fig. 2 Results of the placebo test

times to improve the validity of the test. Figure 2 shows the scatter distribution of the probability density distribution of the coefficient estimates. The coefficient estimates of the placebo test were concentrated at approximately 0, most of which were not significant, and the estimation results of the benchmark regression were not included in the test results. This shows that the conclusions of this study were not affected by other non-observed variables.

To further ensure the robustness of the regression results, the following tests were conducted. First, parallel trend tests were conducted. The results are shown in Table 5, where the parallel trend hypothesis was met before the GCP. In contrast, the estimated coefficients for each year after the implementation of the policy were significantly negative (although the degree of significance varies between years), indicating that GCP will affect the innovation level of enterprises in the long term and limit their innovation ability. In addition, GCP implementation had a dynamic impact on corporate green innovation, with the impact of the GCP gradually becoming significant from the second year of implementation, suggesting that the influence of the policy on restricting green credit is enhanced over time. The long-term implementation of GCP has a greater inhibitory effect on corporate green innovation.

Table 5 Parallel trend test results

Variable	*LnTotal* (1)	*LnInva* (2)
Treat × Year_2010	−0.075	−0.099
	(0.045)	(0.059)
Treat × Year_2011	−0.085	−0.106
	(0.046)	(0.059)
Treat × Year_2012	−0.123***	−0.146**
	(0.047)	(0.061)
Treat × Year_2013	−0.096*	(0.061)
	(0.051)	(0.065)
Treat × Year_2014	−0.106**	−0.115*
	(0.052)	(0.067)
Treat × Year_2015	−0.157**	−0.180**
	(0.056)	(0.070)
Treat × Year_2016	−0.157***	−0.178**
	(0.059)	(0.074)
Constant	−4.149***	−5.022***
	(0.508)	(0.598)
Controls	Yes	Yes
Year FE	Yes	Yes
Industry FE	Yes	Yes
N	11,679	11,679
R^2	0.204	0.204

***, **, *Represent 1, 5 and 10%, respectively

To avoid estimation bias caused by sample selection errors, this study used the propensity score matching method to test robustness. *Inst, LnEmployee, Largest, LnDebt, LnAge, LnSize, LnRD, Grow, Flow, Cash, Fasset,* and *Tobin Q* were selected as characteristic variables, a logit model was used to estimate the probability of each sample being included in the experimental group, and then the caliper nearest neighbor matching method was used as the control group with reasonable matching. Table 5 presents the results of the PSM-DID model. It can be observed that the research conclusions are robust.

Table 6 also shows the results of replacing dependent variables with the proportion of green patents in all patent applications (*Total_n*), the proportion of green invention patent applications in all patent applications (*Inva_n*), and the proportion of green utility model patent applications in all patent applications (*Uma_n*). The effects of GCP on total green innovation output and green invention patents are significantly negative. However, the effect on green utility model patents is significantly positive with the inclusion of the control variables. This indicates the potential for GCP to promote increased utility model patent innovation in green credit-restricted firms.

Third, corporate innovation is a high-risk activity, and significant and substantial innovations that can bring about technological progress and product upgrades usually take a long time. Referring to He and Tian (He and Tian 2013), this study selected the value of *LnTotal* in year t + 1, year t + 2, and year t + 3 to measure corporate green innovation, and the results are shown in Table 7. After considering the long-term nature of the green innovation process, the effects of the GCP on the number of green patent applications were all significantly negative, and the effects on the number of green invention patent applications were all significantly negative, at least at the 5% level. These results are consistent with the benchmark results.

Table 6 The results of replacing the dependent variables and PSM-DID

Variable	*PSM-DID* (1)	*Total_n* (2)	*Uma_n* (3)	*Inva_n* (4)
Policy × *Treat*	− 0.131***	− 0.006**	0.004**	− 0.012**
	(0.042)	(0.003)	(0.002)	(0.006)
Constant	− 1.478***	− 0.025	− 0.116***	0.051
	(0.423)	(0.020)	(0.026)	(0.040)
Controls	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
N	11,559	11,679	11,679	11,679
R^2	0.202	0.077	0.022	0.077

***, **, *Represent 1, 5 and 10%, respectively

Table 7 Robustness tests

Variable	*L1lnTotal* (1)	*L2lnTotal* (2)	*L3lnTotal* (3)	*L1lnInva* (4)	*L2lnInva* (5)	*L3lnInva* (6)
Policy × Treat	−0.128***	−0.113***	−0.087***	−0.136***	−0.118***	−0.092**
	(0.026)	(0.027)	(0.031)	(0.033)	(0.035)	(0.039)
Constant	−1.918***	−1.822***	−1.637***	−2.338***	−2.293***	−2.086***
	(0289)	(0.319)	(0.346)	(0.365)	(0.405)	(0.442)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
N	10,728	9837	8944	10,728	9837	8944
R^2	0.202	0.172	0.141	0.201	0.171	0.140

***, **, *Represent 1, 5 and 10%, respectively

Table 8 Regression results of the mediating effect of debt financing

Variables	*Floan* (1)	*LnTotal* (2)	*Flloan* (3)	*LnTotal* (4)
Policy × Treat	−0.020***	−0.086***	−0.020***	−0.088***
	(0.004)	(0.030)	(0.003)	(0.030)
Floan		−0.684***		
		(0.082)		
Flloan				−0.785***
				(0.116)
Constant	0.198***	−6.231***	−0.342***	−6.635***
	(0.033)	(0.269)	(0.021)	(0.276)
Controls	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
N	11,679	11,679	11,679	11,679
R^2	0.584	0.384	0.462	0.382

***, **, *Represent 1, 5 and 10%, respectively

5.3 Mechanism analysis

Table 8 shows the mediating effect of lending constraints on the GCP's impact on corporate green innovation. As shown in columns (1) and (3), the coefficients are −0.020 and −0.020, respectively, all of which pass the 1% significance tests. This indicates that after the implementation of the GCP, the level of loans available to the green credit-restricted enterprises were both significantly lower compared to non-green credit-restricted enterprises and that the GCP significantly suppressed the level of debt financing of the green credit-restricted enterprises, making it more difficult to obtain short-term or long-term loans from banks and other financial institutions. The regression results in columns (2) and (4) are also significantly negative at a 1% confidence level. The absolute value of the coefficients decreases compared to that of the coefficients in Model (1), suggesting that green patent applications by green credit-restricted firms decline less after controlling for firms' access to finance from banks and after the implementation of the GCP. Thus, the GCP influences firms' green innovation activities by affecting their financing constraints and hence their green innovation activities. According to the analysis of Wen and Ye (2014), this study uses Bootstrap to test the mediation effect, and the Bootstrap result shows that the confidence interval of the coefficient does not include 0, and the mediation effect holds. The study suggests that the GCP discourages green innovation among green credit-restricted firms by reducing long-term and short-term debt financing. Therefore, Hypothesis 2 is verified.

5.4 Heterogeneity analysis

The financing constraints imposed by enterprise heterogeneity on green credit are also significantly different due to the influence of property rights. Compared to non-SOEs, SOEs are subject to fewer financing constraints, and both face different degrees of credit discrimination. This study further analyses the impact of firm heterogeneity and divides the sample into subsamples of SOEs and non-SOEs by grouping regressions on the ownership of listed companies. Columns (1) and (2) of Table 9 show the regression results for grouping SOEs and non-SOEs. From the coefficients of the cross-products in Table 9, the effect of enterprise heterogeneity on the implementation of the GCP is significantly different. The inhibitory effect of GCP on non-SOEs' green innovation activities is more significant than that of SOEs, indicating that the difference in property rights leads to more severe financing

Table 9 Heterogeneity tests

Variable	*LnTotal* SOEs (1)	*LnTotal* Non-SOEs (2)	*LnInva* SOEs (3)	*LnInva* Non-SOEs (4)
Policy × *Treat*	−0.007	−0.202***	0.018	−0.238***
	(0.064)	(0.053)	(0.078)	(0.066)
Constant	−1.206**	−1.664***	−1.343**	−2.110***
	(0.542)	(0.422)	(0.667)	(0.510)
Controls	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
N	6171	5508	6171	5508
R^2	0.398	0.321	0.403	0.327

***, **, *Represent 1, 5 and 10%, respectively

constraints for non-state-owned green credit-restricted firms. However, the inhibitory effect on SOEs' innovation is relatively small. Therefore, the implementation of the GCP is credit-discriminatory for both state-owned and non-state-owned green credit-restricted listed companies, indicating that the GCP cannot fundamentally change the credit status of SOEs and non-SOEs. Hypothesis 3 is verified.

6 Conclusion and policy implications

Green innovation is an important strategy for companies to achieve sustainable development goals. In addition to helping companies create a green image and improve their competitive advantage, green innovation can also reduce pollution and improve the ecological social environment, with positive external effects. Developing countries, such as Brazil, Malaysia, and India, have made significant efforts to promote green innovation. Chinese companies have also attached great importance to green innovation. China is striving to achieve its goal of building a market-oriented system of green scientific and technological innovation by 2022. As an important financial control instrument to promote green development, it impacts the decision-making and innovation of companies' behavior. This study gathered data from non-financial listed companies in China's A-share market from 2007 to 2019, constructed a quasi-natural experiment with Green Credit Guidelines, and tested the impact of GCP on corporate green innovation using the DID method. The results strongly show that the GCP inhibits green credit-restricted firms' innovative activities as a whole compared to clean firms and has a significant negative impact on the total amount of green innovation and quality of green innovation. The increased credit constraint caused by the contraction of long- and short-term lending is the main mechanism involved. This suggests that enterprises exhibit strategic green innovation behavior when faced with GCP. Green credit-restricted firms' strategic choices aim not to improve their own substantive innovation capabilities but only to alleviate financing constraints. However, this study has some limitations. Innovation quality includes three levels: product or service, process, and the firm level (Chaithanapat et al. 2022). Although the selection of innovation quality indicators used in this study is representative, it is not comprehensive. How green credit policies affect enterprises' innovation quality is a topic for future research. In particular, in the post-COVID-19 era, the importance of green finance in promoting green economic recovery and corporate innovation is more prominent but limited by time and data access; this study does not quantify this, which is also a focus of future research.

The GCP aimed to improve green economic development. The ultimate goal is to promote the transformation and upgradation of heavy polluters and accelerate green innovation. Accordingly, developing countries still have opportunities to improve their efficiency in the process of developing green financing, especially green credit. First, the GCP does not promote green innovation in green credit-restricted firms but increases credit constraints and reduces the possibility of green innovation.

Although this constraint can reduce environmental risks in the short term, it is not conducive to long-term development or green transformation. This “one size fits all” policy is more common in developing countries (Lessmann and Markwardt 2010). The corporate green financing dilemma has become even more prominent in the post-COVID-19 era. Therefore, corporate credit constraints can be better mitigated by diversifying financing channels (Taghizadeh-Hesary et al. 2022a), such as issuing green bonds (Rasoulinezhad and Taghizadeh-Hesary 2022) and establishing green credit guarantee companies (Taghizadeh-Hesary et al. 2022b). Studies have shown that FDI can effectively enhance green economic growth (Phung et al. 2022). To improve financing efficiency, the government can implement tax exemptions and subsidies and establish green economic zones to attract foreign direct investment. Policymakers should also encourage the private sector to participate in green project investments (Rasoulinezhad 2020) and establish a clearer, long-term plan that reconciles financial reform, corporate finance, and corporate innovation (Yoshino et al. 2021).

Second, for commercial banks, the investment bodies of the green finance system need to be more diversified to pay attention to the possible borrowing and financing behaviors of enterprises in all links, from production to consumption. Financial institutions should provide more convenient services for the green development of enterprises and should not simply classify the industries to which enterprises belong to the credit threshold. Financial institutions need more refined operations for green loans to enterprises and should pay more attention to the essence of green innovation. Support for a green financing system for enterprises’ green innovation should be universal. Regulators should urge banks to consider the environmental protection information of enterprise credit projects as an important basis for green credit management.

Third, enterprises must be socially responsible. The development of renewable energy technologies in the green innovation of enterprises can not only promote green recovery but also reduce unemployment (Saboori et al. 2022). Enterprises must strengthen corporate governance, particularly green governance. They must proactively disclose information on environmental protection and social responsibility, increase their sensitivity to green financial policies, and gain more green financial support from financial institutions. Moreover, stakeholders should be fully motivated to monitor corporate environmental decisions both to prevent managers from taking advantage of environmental costs for personal gain and to promote the efficiency of enterprises in using funds to improve the level of green innovation.

Appendix A

See Table 10.

Table 10 Correlation analysis

	(1)	(2)	(3)	(4)	(5)	(6)
(1) LnTotal	1					
(2) LnInva	0.996***	1				
(3) Treat	−0.058***	−0.052***	1			
(4) Reform	0.209***	0.216***	−0.001	1		
(5) Treat × Reform	0.033***	0.042***	0.712***	0.427***	1	
(6) LnAge	0.079***	0.081***	−0.042***	0.562***	0.213***	1
(7) LnSize	0.204***	0.203***	0.020**	0.097***	0.054***	0.078***
(8) LnDebt	0.100***	0.099***	−0.065***	−0.013	−0.074***	0.052***
(9) Grow	−0.017*	−0.017*	−0.051***	−0.025***	−0.049***	−0.007
(10) LnEmployee	0.403***	0.403***	0.136***	0.168***	0.152***	0.020**
(11) Inst	0.183***	0.182***	0.005	0.234***	0.104***	0.159***
(12) Largest	0.041***	0.039***	0.016*	−0.058***	−0.011	−0.160***
(13)LnRD	0.349***	0.362***	0.146***	0.374***	0.285***	0.091***
(14)Fasset	−0.016*	−0.012	0.410***	−0.086***	0.254***	−0.129***
(15) Flow	0.002	−0.001	−0.302***	−0.020**	−0.224***	−0.033***
(16) Cash	−0.018*	−0.022**	−0.130***	−0.099***	−0.118***	−0.127***
(17) Tobin Q	−0.108***	−0.110***	−0.020**	−0.040***	−0.046***	−0.033***

	(7)	(8)	(9)	(10)	(11)	(12)
(1) LnTotal						
(2) LnInva						
(3) Treat						
(4) Reform						
(5) Treat × Reform						
(6) LnAge						
(7) LnSize	1					
(8) LnDebt	0.374***	1				
(9) Grow	−0.084***	0.025***	1			
(10) LnEmployee	0.349***	0.249***	−0.005	1		
(11) Inst	0.216***	0.082***	−0.015	0.299***	1	
(12) Largest	0.136***	0.083***	0.093***	0.156***	0.378***	1
(13) LnRD	0.210***	−0.026***	−0.062***	0.351***	0.134***	−0.032***
(14) Fasset	0.021**	0.025***	−0.080***	0.217***	−0.020**	0.041***
(15) Flow	−0.043***	0.093***	0.080***	−0.123***	−0.01	0.01
(16) Cash	−0.091***	−0.342***	0.005	−0.102***	0.044***	0.008
(17) Tobin Q	−0.210***	−0.311***	−0.027***	−0.286***	0.032***	−0.112***

	(13)	(14)	(15)	(16)	(17)
(1) LnTotal					
(2) LnInva					
(3) Treat					
(4) Reform					
(5) Treat × Reform					

Table 10 (continued)

	(13)	(14)	(15)	(16)	(17)
(6) LnAge					
(7) LnSize					
(8) LnDebt					
(9) Grow					
(10) LnEmployee					
(11) Inst					
(12) Largest					
(13) LnRD	1				
(14) Fasset	0.008	1			
(15) Flow	0.049***	−0.683***	1		
(16) Cash	0.001	−0.290***	0.377***	1	
(17) Tobin Q	−0.016*	−0.089***	0.079***	0.236***	1

Appendix B

See Table 11.

Table 11 Panel unit root tests (variable in levels)

	Statistic	Prob.**	Status
LnTotal	5044.7713***	0.0000	I(0)
LnInva	5187.0764***	0.0000	I(0)
LnAge	1966.9878**	0.0071	I(0)
LnSize	5159.7168***	0.0000	I(0)
LnDebt	5513.3738***	0.0000	I(0)
Grow	6999.3557***	0.0000	I(0)
LnEmployee	4526.9972***	0.0000	I(0)
Inst	7251.4423***	0.0000	I(0)
Largest	4732.3308***	0.0000	I(0)
LnRD	7662.8291***	0.0000	I(0)
Fasset	5520.8741***	0.0000	I(0)
Flow	5303.4756***	0.0000	I(0)
Cash	5904.7635***	0.0000	I(0)
Tobin Q	6792.2458***	0.0000	I(0)

Funding This research was supported by The National Social Science Foundation of China (The Funding Number: 22CJL033).

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