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WUENQIQIGE

THE IMPACT OF GREEN CREDIT POLICY ON CORPORATE GREEN TECHNOLOGICAL INNOVATION —A STUDY BASED ON CHINESE LISTED COMPANIES

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041301

Business Administration

Doctoral dissertation

Supervisor
Purevdulam Altantsetseg, Ph.D./ Associate Prof.

Ulaanbaatar. 2026

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Supervisor

Purevdulam Altantsetseg, Ph.D./ Associate Prof.

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Ulaanbaatar. 2026

STATEMENT

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LIST OF ABBREVIATIONS

IEA: International Energy Agency

OECD: Organization for Economic Co-operation and Development

ESG: Environmental, Social and Governance

WCED: World Commission on Environment and Development

UNEP: United Nations Environment Programme

HUD: Federal Department of Housing and Urban Development

ESRM: Environmental and social risk management system

UKETS: UK Emissions Trading Scheme

WIPO: World Intellectual Property Organization

CSGT: China Society for Green Trade

MEI: Measuring Eco-Innovation

IPCC: Intergovernmental Panel on Climate Change

AFOLU: Agriculture, Forestry and Other Land Use

UNEP-CCC: United Nations Environment Programme – Climate Change Coordination

CCICED: China Council for International Cooperation on Environment and Development

IPC: International Patent Classification

RBV: Resource-Based View

NRBV: Natural Resources Fundamental View

DID: Difference-in-Differences Model

CNRDS: China Research Data Service Platform

TERMINOLOGY/DEFINITION

Green credit refers to incorporating environmental factors into the credit review standards of financial institutions, providing low-interest loans to green, low-carbon, energy-saving and environmental protection industries, and providing high-interest loans to heavily polluting industries while limiting their credit lines.

Green technology innovation typically refers to technological progress and creation with the core objectives of promoting sustainable development and improving environmental quality. This means using technological advancements to reduce energy consumption, reduce pollution emissions, improve resource utilization, and support ecological and environmental protection.

R&D investment refers to the funds, human resources, and material resources that enterprises allocate to carry out research and experimental development activities, promote technological progress, and generate innovative outputs. Its core manifestation is research and development expenditure.

Financing constraints are a financial constraint state in which a company is unable to obtain the financial support to meet its investment needs when there is friction between its internal funds and external financing, thus preventing it from fully realizing its optimal investment, R&D innovation, or production and operation activities.

Corporate information disclosure is an important channel for stakeholders and institutional investors to understand the basic operating conditions of a company, while corporate environmental information disclosure focuses on disclosing the company's environmental information, which helps to solve the problem of environmental information asymmetry and makes it easier for companies to obtain external investment support.

The difference-in-differences (DID) model is a commonly used method for policy evaluation and causality identification. It is used to compare the differences in outcome variables between the treatment group and the control group before and after the implementation of a policy, thereby identifying the net effect of the policy or external shock.

Green invention patents refer to invention patents that enterprises have been authorized or applied for in the fields of energy conservation and environmental protection, clean energy, pollution control, and resource recycling. They are used to measure the quality and depth of an enterprise's green technology innovation.

Green utility model patents refer to utility model patents applied for or obtained by enterprises in the fields of energy conservation and environmental protection, pollution prevention and control, resource recycling and cleaner production, which are used to measure the level of enterprise innovation in green technology application and improvement.

Institutional investor shareholding refers to the total number of shares held by various institutional investors in the company or the proportion of the company's total share capital during the reporting period, which is used to measure the degree of institutional investor participation in the company's shareholding.

Executive Financial Background refers to the financial-institution work experience, finance-related educational background, or financial investment management experience of a firm’s senior managers, and is used to measure the management team’s professional capability in obtaining financial resources, allocating capital, and making financing decisions.

Capital intensity refers to the degree of concentration of capital input in the production and operation process of an enterprise. It is usually used to measure the degree of dependence of an enterprise on capital resources such as fixed assets.

LIST OF SEMINARS

1. UFE Research seminar-I, “Discussion on theoretical basis ,” November 13, 2025
2. UFE Research seminar-II, “ Discussion on and research methodology” December 12, 2025
3. UFE Academic Symposium, “Discussion on approval of dissertation topic” December 15, 2025
4. UFE Development seminar,“Discussion on empirical analysis results”January 13, 2026
5. UFE Extended Seminar,“Discussion on research findings and recommendations,” February 2, 2026
6. UFE Advisory Committee Meeting, “Discussion and decision to go into pre-defense Preparation,” February 9, 2026

Хураангуй

БНХАУ-ын эдийн засаг тасралтгүй хөгжихийн хэрээр байгаль орчныг хамгаалах асуудал улам бүр хурцаар тавигдаж, ногоон тогтвортой хөгжил нь өнөөгийн чухал сэдэв болоод байна. Ногоон технологийн инноваци нь нүүрстөрөгчийн оргил үе болон нүүрстөрөгчийн саармагжилтын зорилтыг хэрэгжүүлэх чухал алхам бөгөөд эрчим хүчний бүтцийг илүү бохирдол багатай болгох, аж үйлдвэрийн бүтцийг бага нүүрстөрөгч ялгаруулах чиглэлийг шинэчлэн сайжруулахад дэмжлэг үзүүлдэг. Аж ахуйн нэгжүүдийн эрчим хүч хэмнэх, нүүрс хүчлийн хНийн ялгарлыг бууруулах гол түлхүүр нь технологийн инноваци бөгөөд технологийн инновацийг хэрэгжүүлэхэд санхүүжилт болон хүний нөөцийн хосолсон дэмжлэг зайлшгүй шаардлагатай. Үүний зэрэгцээ, аж ахуйн нэгжүүд ногоон технологийн инновацийн явцад санхүүгийн хязгаарлалт болон инновац хийх сэдэл дутмаг байх зэрэг нийтлэг хүндрэлтэй тулгарч байна. “2024 оны Хятадын патентийн судалгааны тайлан”-д дурдсанаар, ногоон технологийн инноваци хэрэгжүүлээгүй аж ахуйн нэгжүүдийн 42.7 хувь нь шаардлагатай судалгаа, хөгжүүлэлтийн хөрөнгө дутмаг байгааг ногоон технологийн инноваци явуулахад тулгарч буй гол саад гэж үзсэн байна.

Энэхүү судалгаа нь 2012 онд батлагдсан “Ногоон зээлийн удирдамж”-ийг бодлогын гол чиглэл болгон авч үзэж, 2006–2024 оны хоорондын хөрөнгийн бирж дээрх бүртгэлтэй компаниудыг анхны түүвэр болгон сонгосон. Тогтвортой хөгжлийн онолыг гол онолоо болгон судалгааны хүрээ болгон ашиглаж, ялгааны давхар ялгааны загвар (DID)-ыг хэрэглэн ногоон зээлийн бодлогын хэрэгжилт нь бүртгэлтэй компаниудын ногоон технологийн инновацийн үйл ажиллагаанд хэрхэн нөлөөлж байгааг судлав. Судалгааны үр дүнгээс харахад: (1) ногоон зээлийн бодлого нь аж ахуйн нэгжүүдийн ногоон инновацийн үйл ажиллагааг дэмжихэд мэдэгдэхүйц эерэг нөлөө үзүүлдэг бөгөөд ногоон бүтээлийн патенттай харьцуулахад ногоон ашигтай загварын патентыг дэмжих нөлөө нь илүү хүчтэй байна; (2) зуучлагч нөлөөний шинжилгээний үр дүнгээс үзэхэд байгаль орчны мэдээллийн ил тод байдлын түвшний зуучлагч нөлөө онцгой ач холбогдолтой байна; (3) зохицуулагч механизмын шинжилгээ нь институцийн хөрөнгө оруулагчдын хувьцаа эзэмшил нь ногоон зээлийн бодлого ба

аж ахуйн нэгжийн ногоон технологийн инновацийн хоорондын хамааралд чухал зохицуулах үүрэг гүйцэтгэж байгааг харуулсан; (4) ялгаварт шинжилгээ нь төрийн өмчит аж ахуйн нэгж, томоохон аж ахуйн нэгж, үйлдвэрлэлийн аж ахуйн нэгж болон өндөр капиталын нягтралтай аж ахуйн нэгжүүдэд ногоон зээлийн бодлого нь тэдгээрийн ногоон инновацийн үйл ажиллагаанд илүү мэдэгдэхүйц дэмжих нөлөө үзүүлж байгаа үр дүн гарсан.

Дээрх үр дүнд үндэслэн энэхүү докторын судалгаа дараах санал, зөвлөмжийг дэвшүүлж байна. Засгийн газар ногоон зээлийн тогтолцооны хүрээг цаашид улам боловсронгуй болгож, бодлогын хяналт, зохицуулалтыг бэхжүүлэхийн зэрэгцээ том, жижгээс үл хамааран ногоон технологийн инновац хийж буй аж ахуйн нэгжүүдийг дэмжих шаардлагатай. Банкнууд аж ахуйн нэгжүүдийн ногоон технологийн инновацийн хэрэгцээг үнэн зөв үнэлж, ногоон инновац хийж буй аж ахуйн нэгжүүдэд үзүүлэх зээлийн дэмжлэгээ нэмэгдүүлэхийн хамт ногоон зээлийн эрсдэлийн удирдлагын иж бүрэн тогтолцоог бүрдүүлэх хэрэгтэй байна. Аж ахуйн нэгжүүд ногоон технологийн судалгаа хөгжүүлэлтэд оруулах хөрөнгө оруулалтаа нэмэгдүүлж, байгаль орчны мэдээллийн ил тод байдлыг сайжруулан, өөрсдийн онцлогт нийцүүлэн санхүүжилтийн бүтцээ оновчтой болгож, ногоон технологийн инновацийн стратегиа боловсруулах шаардлагатай юм.

Түлхүүр үгс: ногоон зээлийн бодлого; аж ахуйн нэгжийн ногоон технологийн инноваци; байгаль орчны мэдээллийн ил тод байдал; судалгаа, хөгжүүлэлтийн хөрөнгө оруулалт

ABSTRACT

With the continuous development of China's social economy, environmental protection issues have become increasingly prominent, and green and sustainable development has become an important topic. Green technology innovation is an important way to achieve carbon peaking and carbon neutrality goals, and it helps to promote the clean energy structure and the low-carbon transformation and upgrading of the industrial structure. The key to energy conservation and emission reduction for enterprises lies in technological innovation, which requires both financial and talent support. At the same time, enterprises generally face financial constraints and insufficient innovation motivation in the process of green technology innovation. According to the "2024 China Patent Survey Report," among enterprises that have not carried out green technology innovation, 42.7% indicated that the lack of necessary R&D funds was the main obstacle to their green technology innovation.

This paper takes the "Green Credit Guidelines" promulgated in 2012 as a quasi-natural experiment, selects A-share listed companies from 2006 to 2024 as the initial sample, uses sustainable development theory as the overall analytical framework, and employs a difference-in-differences model to examine the impact of the implementation of green credit policies on the green technology innovation activities of listed companies. The study shows that: (1) Green credit policies have a significant positive impact on promoting green innovation activities of enterprises, and their promotion effect on green utility model patents is more significant than that on green invention patents; (2) The mediation effect analysis results show that the mediation effect of the level of environmental information disclosure is particularly significant; (3) The moderating mechanism analysis shows that institutional investor shareholding plays a key moderating role in the relationship between green credit policies and corporate green technology innovation; (4) The heterogeneity analysis reveals that green credit policies have a more significant promoting effect on the green innovation activities of state-owned enterprises, large enterprises, manufacturing enterprises, and capital-intensive enterprises.

Based on the above conclusions, this paper proposes the following recommendations: the government should continue to optimize the green credit system framework, strengthen policy

guidance and supervision, and coordinate the development of enterprises of all sizes; banks should accurately assess enterprises' needs for green technology innovation, increase credit support for green innovation enterprises, and establish a sound green credit risk management system; enterprises should increase investment in green technology research and development, strengthen environmental information disclosure, optimize their financing structure according to their own characteristics, and formulate green technology innovation strategies.

Keywords: Green credit policy; Corporate green technological innovation; Environmental information disclosure; R&D investment

Introduction

Research Background

As global climate change and ecological environmental challenges continue to intensify, green development has become a widely shared consensus within the international community. Since the United Nations proposed the goals of “green, low-carbon, and sustainable” development in the 2030 Agenda for Sustainable Development, countries around the world have increasingly used financial instruments to guide resource allocation toward green industries. As an essential component of the financial system, green finance plays a critical role in promoting environmental protection, energy transition, and technological innovation. Among its various instruments, green credit is one of the earliest-developed and most influential core tools within the green finance framework. By establishing environmental access standards and implementing differentiated interest rates and credit policies, green credit performs a dual "incentive and constraint"function in financial resource allocation, guiding firms to reduce investments in highly polluting and energy-intensive activities while fostering green technological innovation and cleaner production.

In China, the development of green credit has been closely linked to policy support. Since the former State Environmental Protection Administration, the People’s Bank of China, and the China Banking Regulatory Commission jointly issued the Green Credit Guidelines in 2007, China’s green credit policy framework has been progressively improved, and the outstanding balance of green loans has continued to grow. According to data from the People’s Bank of China, by the end of 2024, the outstanding balance of green loans in both domestic and foreign currencies nationwide had exceeded RMB 36 trillion, representing a year-on-year increase of more than 30%, with the share of green loans in total lending steadily rising. Green credit policies have increasingly demonstrated their role in guiding corporate green transformation and supporting clean energy development, energy conservation and emissions reduction, as well as the construction of environmental protection infrastructure. At the same time, green credit policy has gradually become an important instrument within China’s financial system for advancing supply-side structural reform and achieving the “dual carbon” goals.

On the other hand, corporate green technological innovation is a key pathway for achieving green transformation and carbon reduction goals. Compared with traditional technological innovation, green technological innovation not only pursues economic returns but also emphasizes environmental benefits and social responsibility, serving as an important driving force for enhancing corporate competitiveness and achieving sustainable development. However, green technological innovation is characterized by high investment requirements, long development cycles, and elevated risks, which often subject firms to financing constraints and insufficient innovation incentives. Owing to information asymmetry and the difficulty of quantifying environmental benefits, the traditional financial system has tended to provide limited support for green innovation activities. Consequently, whether green credit policies can effectively stimulate corporate green technological innovation by optimizing financing structures, reducing the costs of green innovation, and enhancing the transparency of environmental information has become a core issue of widespread concern among both academics and policymakers.

Existing research has confirmed at the macro level that green finance can promote industrial upgrading, environmental governance performance, and regional green efficiency; however, at the micro level, especially regarding the mechanisms and differences in how green credit policies affect corporate green technology innovation, systematic empirical testing is still lacking. On the one hand, the transmission mechanisms of green credit and other financial instruments such as green bonds differ, potentially leading to heterogeneity in corporate innovation responses; on the other hand, factors such as corporate ownership, industry attributes, and the regional financial environment also influence the effectiveness of policy implementation. Therefore, it is necessary to delve deeper into how green credit policies influence corporate green technology innovation through resource allocation and incentive constraints. This research will not only enrich green finance theory but also provide strong evidence for optimizing policy design, improving innovation efficiency, and promoting high-quality development.

In summary, against the backdrop of the continuous improvement of China’s green finance system and the comprehensive advancement of the “dual carbon” goals, a systematic examination of the effects of green credit policies on corporate green technological innovation is not only of significant theoretical value but also of substantial practical relevance. On the one hand, this research enriches the theoretical foundations of green finance and green innovation by elucidating the role and underlying logic of financial instruments in fostering corporate green innovation. On the other hand, it provides empirical evidence to support the formulation of more targeted green credit policies by the government, the promotion of corporate green innovation practices, and the achievement of the "dual carbon" objectives.

Research Problem

As global climate change and environmental problems continue to intensify, green development has become a central issue in the global economy. In particular, promoting green transformation has become an urgent priority for major economies. The G7 countries occupy an important position in the global economy, accounting for 26.6% of global GDP in 2023. According to data from IEA, energy-related carbon dioxide emissions of the G7 countries in 2023 were as follows: the United States, 4,413 million tons of CO_2; Japan, 935 million tons of CO_2; Germany, 549 million tons of CO_2; Canada, 523 million tons of CO_2; the United Kingdom, 289 million tons of CO_2; Italy, 284 million tons of CO_2; and France, 263 million tons of CO_2. In 2023, Mongolia's carbon dioxide emissions were approximately 26.04 million tons of CO_2, ranking 109th globally. During the same period, Russia's carbon dioxide emissions reached about 1,691.83 million tons of CO_2, ranking fourth in the world and making it one of the major global carbon emitters. Meanwhile, China has experienced rapid economic growth over the past decade and has consistently maintained its position as the world's second-largest economy. However, this rapid development has also led to problems such as resource depletion, environmental pollution, and ecosystem degradation, posing threats to ecological security and creating severe challenges for sustainable development. As global climate change intensifies, China faces the dual pressures of economic transformation and environmental protection. According to IEA data, China's carbon dioxide emissions reached approximately 11,130 million tons of CO_2 in 2023, setting a historical high and ranking first globally. This level is about 2.5 times that of the United States, the world's second-largest emitter (4,413 million tons of CO_2), highlighting China's significant role in global carbon emissions and the considerable environmental pressures it faces.

According to data from the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP), Mongolia experienced a warming rate of approximately 0.16°C per decade between 1991 and 2016. Data from the China National Climate Center shows that since 1951, China's average annual temperature has shown a significant upward trend, with a warming rate of approximately 0.26°C per decade, higher than the global average (approximately 0.15°C per decade). This indicates that China is one of the most sensitive regions to global climate change.

According to the Global Environmental Performance Index jointly released by the Yale Center for Environmental Law & Policy , the Center for International Earth Science Information Network at Columbia University, and the World Economic Forum , China's rankings in 2012, 2014, 2016, 2018, 2020, 2022, and 2024 were 116th, 118th, 109th, 120th, 120th, 160th, and 156th, respectively. The extensive industrial development model has caused environmental pollution and economic growth to reinforce each other, thereby driving China into a vicious cycle.

From the corporate perspective, the latest data from the Carbon Majors Database show that in 2023 the top 20 companies with the highest global carbon emissions collectively emitted approximately 17.5 one billion tons of carbon dioxide equivalent, accounting for 42.7% of total global carbon dioxide emissions from fossil fuels and cement in that year. The list is dominated by state-owned enterprises, which account for about 80% of the top 20 emitters. Notably, Chinese companies occupy 40% of the list; emissions from these eight firms together accounted for approximately 17.4% of total fossil fuel and cement-related carbon dioxide emissions in that year. In terms of industry composition, coal companies feature prominently on the list, with seven coal firms included, six of which are from China.

As the world's largest developing country, China has long faced severe challenges related to environmental pollution and resource waste, while also being subject to increasingly stringent environmental requirements from the international community. Against this backdrop, the Chinese government has proposed the strategic goals of "carbon peaking" and "carbon neutrality," aiming to reach peak carbon emissions around 2030 and achieve carbon neutrality by 2060. As one of the primary sources of carbon emissions, enterprises not only face unprecedented pressure to reduce emissions but also encounter important opportunities for green transformation and technological innovation, driven jointly by policy constraints and market demand.

Despite the rapid development of green technology innovation in China, research indicates shortcomings in innovation efficiency and quality improvement. For example, Zhou (2023) points out that the efficiency of green innovation is generally low across Chinese provinces, with many provinces achieving an efficiency of only around 0.3. Enterprises face multiple obstacles in promoting green technology innovation, primarily including high initial costs, financing constraints, long payback periods, and uneven implementation of environmental regulations. First, the initial costs of green technologies are high. The World Bank (2023) points out that initial investment in green technologies is typically 20% to 50% higher than that of traditional technologies, while the International Energy Agency (IEA, 2021) considers the capital costs of energy-saving and emission-reduction technologies to be 30% to 70% higher than conventional technologies. Second, enterprises face financing difficulties. Banks are reluctant to approve green projects due to perceived high risks and a lack of sufficient collateral, making financing more difficult. The OECD (2020) report indicates that SMEs face significant financial barriers when adopting clean technologies. Third, the investment payback period for many green technologies is long, typically exceeding 5 to 10 years. The OECD (2020) argues that this leads corporate management to favor projects with shorter-term returns, rather than investing in long-term and uncertain green technologies. Finally, uneven regional policy enforcement means companies face varying levels of environmental regulation in different regions. The World Bank (2018) points out that when enforcement is weak, companies' motivation for green investment significantly decreases, especially when pollution costs are low; companies often choose to "continue polluting" rather than invest in green technologies. These issues collectively hinder the advancement of green technology innovation by enterprises, necessitating effective coordination of policy support, financing channels, and regulatory mechanisms. According to the "2024 China Patent Survey Report," among companies that have not engaged in green technology innovation, 42.7% cited a lack of necessary R&D funding as the primary reason.

Against this backdrop, green credit, as a key financial tool for promoting corporate green transformation and innovation, has gradually attracted widespread attention from policies and the market. Green credit aims to guide capital flows towards energy conservation, environmental protection, and green technology research and development by providing low-interest, long-term funding support to enterprises. However, despite China having the world's largest green credit scale, there is still a lack of consistent empirical evidence regarding its effectiveness in alleviating corporate financing constraints and promoting green technology innovation. Some scholars believe that green credit can significantly reduce corporate financing costs and promote green technology innovation; however, other studies indicate that the policy effects of green credit are not as expected, with some enterprises finding it difficult to fully utilize this policy support due to high thresholds and significant regulatory pressure. Therefore, the actual impact of green credit on corporate green technology innovation still lacks systematic and empirical research.

Based on this, the present study focuses on Chinese listed firms and treats the green credit policy as a quasi-natural experiment to conduct a systematic analysis around the following core questions: How does green credit policy promote corporate green technological innovation? Through which specific mechanisms does it operate? Under what contextual conditions are its effects strengthened or weakened? Addressing these questions not only responds to current policy needs for balancing economic growth and environmental sustainability, but also fills gaps in the existing literature on the relationship between green credit policy and corporate green technological innovation.

Research Questions

Based on the foregoing analysis, this study focuses on the following four core research questions:

Question 1: Does green credit policy significantly promote both the quantity and quality of green technological innovation among Chinese listed firms?

Question 2: Do financing constraints, R&D investment, and environmental information disclosure play mediating roles in the relationship between green credit policy and corporate green technological innovation? Which pathways should be emphasized to enhance policy effectiveness?

Question 3: To what extent do institutional investor ownership and executives' financial backgrounds moderate the impact of green credit policy on corporate green technological innovation? Which moderating factors deserve particular attention?

Question 4: Does the impact of green credit policies on corporate green technological innovation exhibit significant heterogeneity across ownership structure, firm size, and industry categories?

Research Purpose and Research Objectives

The purpose of this study is to use Chinese listed firms as the research sample to systematically examine the impact of green credit policy on corporate green technological innovation, identify its underlying mechanisms (including mediating and moderating effects), and propose recommendations for promoting corporate green technological innovation.To achieve this purpose, the study sets out the following specific objectives:

(1) To explore the theoretical framework and research methods for analyzing the impact of green credit policy on corporate green technological innovation;

(2) To examine the overall effects of green credit policy on green technological innovation among Chinese listed firms;

(3) To analyze the impact pathways, moderating effects, and heterogeneous effects of green credit policy on green technological innovation among Chinese listed firms.

(4) To propose recommendations for optimizing green credit policies to promote green technological innovation among Chinese listed firms.

Significance of the Research

1. Theoretical Significance

First, this paper expands the intersection of research on green finance and corporate innovation. Existing research often analyzes green finance and corporate innovation within separate theoretical frameworks, lacking systematic integration. This paper incorporates green credit policy as an institutional financial tool into the analytical framework of corporate green technology innovation, promoting the integrated development of green finance theory and innovation theory.

Second, , this study deepens the analysis of the mechanisms through which green credit policy influences green technological innovation. Building on an examination of the overall effects of green credit policy, it incorporates financing constraints, R&D investment, and environmental information disclosure into a multiple mediation framework, thereby systematically characterizing the internal mechanisms by which green credit policy affects corporate green technological innovation.

Third, this study enriches the research on the driving factors of corporate green technology innovation. Existing research on the driving factors of green innovation mainly focuses on environmental regulations, market competition, or internal resources, with insufficient discussion on the role of financial policies, especially targeted credit instruments. This study further enriches existing research by empirically examining the direct and indirect impacts of green credit on corporate green technology innovation and its moderating mechanisms.

2. Practical Significance

First, this study provides empirical evidence and decision-making reference for the government to optimize and accurately implement green credit policies. Through empirical analysis, this research assesses the actual impact of green credit policies on green technology innovation in Chinese listed companies, reveals shortcomings and areas for improvement in policy implementation, and provides policymakers with a basis for optimization, helping to more accurately address the difficulties companies face in green technology innovation.

Second, it offers practical and actionable solutions for firms' green transformation and innovation strategies. By uncovering the specific pathways through which green credit influences corporate green innovation, the study provides strategic insights for managers on how to proactively align with green credit policies, optimize financing structures, and plan green technology development, thereby cultivating new sources of competitive advantage while complying with environmental regulations.

Finally, the study contributes to broader societal sustainable development. By encouraging more firms to engage in green technological innovation, it helps reduce pollution and carbon emissions at the source, directly supports initiatives for cleaner air, water, and soil, improves the quality of the living environment, and promotes society's transition toward sustainable development.

Originality of the Research

The innovations of this study can be summarized in three aspects.

First, innovation in theoretical integration. This study will use sustainable development theory as the overall framework, Porter's hypothesis as an aid, and organically integrate environmental risk theory, information asymmetry, resource-based view, financing constraint theory, upper echelon theory, stakeholder theory, and innovation diffusion theory to systematically reveal the path by which external institutional pressures are transformed into green technology innovation achievements through internal resource and capacity allocation.

Second, this study introduces innovation in identifying mechanisms and mediating transmission pathways. Building on the analysis of the overall effect of green credit policy on corporate green technological innovation, it simultaneously incorporates financing constraints, R&D investment, and the level of environmental information disclosure into the transmission mechanism framework, and constructs a multiple mediation model to examine the indirect effects of green credit policy on corporate green technological innovation. Compared with existing studies that focus on a single mediating variable, this approach allows for a more nuanced depiction of the internal mechanisms through which green credit influences corporate green technological innovation.

Third, the study offers innovation in indicator construction and the measurement of green technological innovation. In measuring green technological innovation, this research adopts both quantity and quality dimensions. Based on green patent classifications and relevant patent databases, it constructs multi-level indicators such as “green invention patents” and “green utility model patents,” and assesses corporate green technological innovation from three aspects: the total number of green patents, the number of green invention patents, and the number of green utility model patents. Unlike studies that proxy green innovation using only total patent counts or general innovation indicators, this study provides a more precise measurement of green technological innovation at the indicator level.

Limitations of the Research

First, limitations related to the sample scope. This study focuses on Chinese A-share listed firms and does not include non-listed enterprises in the sample, which prevents a direct assessment of the impact of green credit on green technological innovation among non-listed firms. As a result, the findings of this study may not be readily generalizable to non-listed enterprises.

Second, green credit policies may be subject to interference from other policies during implementation, such as government subsidies, low-carbon city pilot programs, and environmental regulations. These policies may be directly or indirectly related to corporate green innovation, thus affecting the actual effectiveness of green credit policies. Although the empirical results of this study have passed robustness tests such as PSM-DID, which to some extent indicates that some other policy interferences have been controlled, the influence of all potential policy factors cannot be completely eliminated.

Third, the independent variable have certain limitations. This paper uses enterprise dummy variables and policy dummy variables as core explanatory variables, but this setup is insufficient to fully reflect the development level and implementation intensity of green credit policies. Due to the difficulty in obtaining green credit data at the company level, this paper was unable to further investigate the specific impact of the level of green credit development and policy intensity on corporate green innovation.

Fourth, lack of mechanism variables and heterogeneity criteria. The mechanism variables and heterogeneity analysis criteria selected in this text are not the only ones, and other important mechanism variables may still be omitted in this text.

CHAPTER 1. THEORETICAL FOUNDATIONS AND LITERATURE OVERVIEW

This chapter explores green credit, green technological innovation, and the mechanisms through which green credit policy influences corporate green technological innovation, and provides a comprehensive overview of the concepts and theoretical frameworks underlying the present study. The review covers key elements of the research, including research methods, relevant theories, and core concepts, with particular emphasis on the interrelationships among key variables, their practical significance, and their impacts.

1.1 Core Concepts of Green Credit Policy and Green Technological Innovation

1.1.1 Green Credit

Green credit is a core tool in the green finance system and an important institutional arrangement for allocating financial resources to serve ecological civilization construction and high-quality development. Against the backdrop of global efforts to address climate change, promote green and low-carbon transformation, and achieve "dual carbon targets," regulatory authorities in various countries are embedding environmental constraints into credit decision-making processes through policy guidance. This guides commercial banks to implement differentiated credit constraints on high-pollution and high-energy-consuming industries, while providing key support for green industries and green technology innovation. As a result, green credit is gradually developing into a crucial link between the financial system and green development strategies.

1.1.1.1 Origin of Green Credit

The intellectual origins of green credit can be traced back to the global environmental protection movement that emerged in the 1970s. In 1972, the United Nations convened the Conference on the Human Environment in Stockholm, which systematically raised the issue of balancing “environment and development” for the first time and laid an important foundation for the concept of sustainable development. In 1987, the World Commission on Environment and Development provided the first comprehensive definition of sustainable development in the report Our Common Future, describing it as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). The Rio Declaration on Environment and Development, adopted in 1992, further clarified the role of financial support in achieving sustainable development, providing an important theoretical basis for the emergence and development of green finance, particularly green credit.

Since the 1990s, financial institutions in Europe and the United States have begun to proactively incorporate environmental, social, and governance (ESG) standards into their lending activities, marking a transition of green credit from conceptual exploration to institutionalization. Among these institutions, Triodos Bank of the Netherlands, established in 1980, was one of the first to adopt sustainable development as its core operating principle, becoming a representative example of a "sustainable bank." In 1992, the United Nations Environment Programme Finance Initiative (UNEP FI) encouraged commercial banks to establish mechanisms for the identification, assessment, and disclosure of environmental and social risks, further strengthening the financial system's focus on environmental and social responsibility. A key milestone in the evolution of green credit from theory to global practice was the introduction of the Equator Principles. In October 2002, the concept was first proposed in London by the International Finance Corporation and nine major international banks, including ABN AMRO, and was formally implemented in June 2003. As a voluntary set of financial industry standards, the Equator Principles are designed to identify, assess, and manage environmental and social risks in project finance (Equator Principles Association, 2020).

The origins of green credit in China are generally understood as a gradual evolution from "environmentally friendly credit" toward a more formalized green credit system. As early as the mid-1990s, the People's Bank of China issued the Notice on Issues Concerning the Implementation of Credit Policies and the Strengthening of Environmental Protection, which required commercial banks to give greater consideration to environmental factors in credit decision-making. Some studies regard this as an early attempt to embed environmental constraints into China's credit system, providing an institutional foundation for the emergence of the green credit concept (Climate Policy Initiative, 2020).

Most of the literature considers the true starting point of China's green credit system to be the "Joint Opinions of the Three Ministries" issued in 2007. In that year, the former State Environmental Protection Administration, the People's Bank of China, and the China Banking Regulatory Commission jointly released the Opinions on Implementing Environmental Protection Policies and Regulations and Preventing Credit Risks, which explicitly called for linking environmental law enforcement outcomes with credit allocation at the regulatory level and for implementing differentiated credit policies for highly polluting and energy-intensive enterprises. This document is widely regarded as a landmark in the establishment of China's green credit system (Green Finance International Legislation and Reference Research Group, 2017; Ministry of Ecology and Environment, 2007). Based on this, some scholars argue that the concept of "green credit" was formally introduced in China for the first time in this policy document, marking the beginning of a systematic integration of environmental risk identification and constraint mechanisms into bank lending practices (Wu Lichao, 2019).

On this basis, the academic literature generally regards the Green Credit Guidelines issued by the China Banking Regulatory Commission in 2012 as a critical milestone marking the transition of green credit from its formative stage to a phase of institutionalized and standardized development. This document systematically defined the objectives, principles, and management requirements of green credit, requiring banking financial institutions to use green credit as a key instrument to optimize credit structures and prevent environmental and social risks. It is widely viewed as a comprehensive upgrade and refinement of the 2007 "Joint Opinions of the Three Ministries" (CBRC, 2012; King & Wood Mallesons, 2012). Subsequently, a large body of research reviewing the evolution of green credit policy has typically identified the environmentally related credit policies of 1995 as the embryonic stage, the 2007 joint opinions as the institutional starting point, and the 2012 Green Credit Guidelines as an important milestone in institutional consolidation. This perspective outlines the origin and early development trajectory of China's green credit system, characterized by a progression from "conceptual introduction" to "policy formation" and then to "institutional deepening" (Wang Xiaojun & Song Jiaying, 2025; Ba Shusong et al., 2018).

1.1.1.2 Definition of Green Credit

Existing research suggests that the definition of green credit has evolved from "environmentally responsible lending practices" to "institutional arrangements with clear policy attributes and regulatory functions." Early literature primarily viewed green credit from the perspective of sustainable finance and corporate social responsibility, understanding it as an innovative form in which commercial banks proactively embed environmental constraints and social responsibility considerations into traditional lending operations. Subsequently, with the gradual improvement of green finance systems and the strengthening of environmental regulatory policies in various countries, academia has increasingly emphasized the policy tool attributes and regulatory functions of green credit.

Jeucken and Bouma (1999) view green credit as one of the core tools for banks or financial institutions to promote environmental sustainability strategies. They argue that green credit policies, through policy incentives, guide financial institutions to leverage their information advantages, credit resources, and differentiated financing policies to provide targeted funding support for environmentally friendly projects or enterprises. Essentially, it is a credit resource optimization mechanism implemented under strict environmental standards and constraints to prioritize meeting the funding needs of green economic development. Labatt and White (2002) further define green credit as an innovative financial tool for addressing environmental pollution, guiding funds towards environmental protection projects and industries to achieve synergistic development between economic activities and environmental protection. Building on this, Jeucken (2010) emphasizes that green credit is a policy choice for commercial banks to achieve their own sustainable development goals, reflecting their proactive assumption of environmental and social responsibility while pursuing economic benefits.

As the global environmental situation becomes increasingly severe, Baron (2010) specifically defines green credit as "a lending behavior in which banks and financial institutions use the environmental performance and corporate social responsibility of borrowing companies as important benchmarks for loan decisions." Cai Haijing et al. (2019) and Xu Jia and Cui Jingbo (2020) summarize green credit policy as an institutional arrangement that combines "financing constraint incentives" and "investment-oriented incentives," that is, by increasing the financing costs of high-polluting enterprises and improving the availability of financing for green projects, it guides the green reallocation of credit resources between enterprises and industries. Xie Hongjun and Lin Xiaochun (2022) further define it as a market-oriented environmental regulation tool that uses credit resource allocation as the main means to serve the national energy conservation and emission reduction goals. Based on this, Xu Xiaochao et al. (2023) found that when green credit policies are superimposed on strong environmental regulations such as central environmental protection inspections, a synergistic effect is formed, which "forces" enterprises to carry out green technology innovation through external pressure. At the same time, Xu Xiaochao and Zhang Junmei (2023) found that the policy has a more significant innovation incentive effect in areas with stronger environmental law enforcement, highlighting the institutional enforcement and deterrent effect of green credit in a strong regulatory context.

This study defines green credit as follows: Green credit refers to incorporating environmental factors into the credit review standards of financial institutions, providing low-interest loans to green, low-carbon, energy-saving and environmentally friendly industries, and providing high-interest loans to heavily polluting industries (typically including six major industries: coal power, petrochemicals, chemicals, steel, non-ferrous metal smelting, and building materials) while restricting their credit scale. Its core content focuses on two aspects: constraint and incentive effects. On the constraint side, green credit establishes guidelines for commercial banks when providing credit, and imposes penalties such as increasing loan interest rates, suspending loans, delaying loans, or even recalling loans on enterprises and projects that violate energy conservation and environmental protection laws and regulations. On the incentive side, commercial banks support energy conservation and environmental protection projects and related enterprises by adjusting credit policies such as loan types, loan terms, interest rates, and loan amounts.

Green credit is an important financial policy instrument aimed at promoting environmental protection, addressing climate change, and advancing sustainable development.

In this study, green credit policy refers to the practice whereby financial institutions incorporate environmental performance as a key evaluation criterion in their lending activities. Enterprises or projects that meet environmental standards and adhere to sustainable development principles are provided with preferential credit support, while highly polluting, energy-intensive, or ecologically damaging enterprises or projects are subject to credit restrictions, thereby guiding capital flows toward green and low-carbon sectors.

1.1.2 Green Technological Innovation

Green technological innovation is a crucial technological foundation for the green economy and sustainable development strategies. It serves as a key pathway for promoting the green transformation of economic structures, enhancing the efficiency of environmental governance, and achieving the "dual carbon" goals. As an innovation activity that delivers both economic and environmental benefits, green technological innovation has become a major focus of academic research both domestically and internationally.

1.1.2.1 Origin of Green Technological Innovation

Since the 1960s and 1970s, Western countries have successively introduced environmental protection regulations in response to severe environmental pollution and resource constraints, providing the practical conditions for the emergence of the concepts of "green technology" and "green innovation." With the publication of "Silent Spring" (Carson, 1962), society began to recognize the serious ecological consequences brought about by industrialization and technological expansion. In 1972, the United Nations Conference on the Human Environment first articulated the principle of giving equal weight to the environment and development, emphasizing that economic activities must operate within the limits of ecological carrying capacity. This line of thinking laid the intellectual foundation for the subsequent development of the green economy and green innovation.

The formation of the concept of sustainable development further promoted the systematization of green innovation theory. Its landmark document is the report Our Common Future, released in 1987 by the World Commission on Environment and Development. The report provided the first clear definition of sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). In 1992, the United Nations Conference on Environment and Development adopted Agenda 21, which for the first time established, at the international level, the coordinated development of the economy, society, and the environment as a shared objective of all countries. Since then, innovation has been regarded as a key pathway to achieving sustainable development, and "green innovation" has gradually been defined as a process of technological change that creates economic and social value while reducing environmental burdens.

After sustainable development theory provided an overarching direction, the “Porter Hypothesis” in environmental economics offered crucial support for the feasibility and driving mechanisms of green technological innovation, challenging the traditional view that environmental protection inevitably increases costs and undermines competitiveness. Conventional wisdom holds that stringent environmental regulations raise compliance costs and thereby weaken firms’ market positions. However, in Toward a New Conception of the Environment–Competitiveness Relationship, Michael Porter and Claas van der Linde (1995) argued that, when well designed, environmental regulations can stimulate innovation through an “innovation offset” effect, encouraging firms to innovate in process improvements, resource efficiency, and green product development. Such innovations can not only offset compliance costs but may even generate additional economic returns, thereby achieving a “win–win” outcome of improved environmental performance and enhanced competitive advantage.

Consequently, environmental regulation has been redefined as an innovation-inducing institutional arrangement rather than merely a source of cost pressure. This perspective provides the core economic logic for explaining why firms may proactively engage in green technological innovation and has shifted related research from normative analysis toward data-driven empirical testing (Ambec et al., 2013).

Entering the 21st century, with the intensification of global climate change and the promotion of the low-carbon economy concept, green technology innovation has begun to become a new direction for national strategy and corporate competition. At the international level, the European Union proposed the "Green New Deal," guiding technological innovation and promoting the green transformation of the economy through policy and financial support. In China, since the implementation of the "Green Credit Policy" in 2007, the financial system has been given an important function of supporting green innovation, promoting enterprises' green technology research and development and application through credit, investment, and risk pricing mechanisms. Studies by Pichlak et al. (2021) emphasize in their review that ecological innovation not only responds to environmental and social issues but also includes systemic changes in products, processes, and business models, making it an important strategic choice for enterprises to cope with sustainable development pressures and market opportunities.

In summary, the origins of green technological innovation reflect a historical process in which human society progressed from the awakening of environmental awareness to the maturation of the concept of sustainable development, and further toward the deep integration of technological innovation with institutional innovation. It represents both a reflection on and a correction of traditional industrial civilization, as well as an inherent requirement for achieving high-quality economic development. Green technological innovation is no longer merely a tool for environmental governance; rather, it has become a key driving force for structural transformation of the economic system and for advancing ecological civilization.

1.1.2.2 Definition of Green Technological Innovation

(1) Green Technology

The Organization for Economic Co-operation and Development (OECD, 2009) defines green technology as a set of technologies used to “monitor, prevent, reduce, or minimize environmental damage and to address waste and pollution issues,” covering the entire technological chain from environmental monitoring to pollution control. The United Nations Environment Programme (UNEP, 2011) places greater emphasis on outcomes, defining green technology as technologies that “protect the environment, generate less pollution, use resources in a more sustainable manner, and enable more effective recycling of waste and products compared with alternative technologies,” thereby highlighting dimensions of resource efficiency and circularity. The World Intellectual Property Organization (WIPO, 2023), through its green technology classification system, implicitly adopts a purpose-oriented definition, viewing green technologies as those “aimed at addressing environmental challenges, particularly those related to climate change, energy, waste management, water resource protection, and agriculture.” This reflects the global focus on pressing environmental issues, especially climate change.

In academic research, green technology is often defined within the framework of "environmental innovation" or "ecological innovation." Ashraf (2020) defines it as a technological approach developed and adopted in an eco-friendly manner, aiming to reduce environmental damage and promote sustainable development. Lohar et al. (2022) point out that the rise of green technology stems from pressures such as climate change and energy depletion, and its role has expanded from solely environmental protection to a comprehensive tool that considers economic, social, and environmental performance. The MEI project led by Kemp et al. (2005) takes an outcome-oriented approach, defining ecological innovation as new or significant improvements in products, processes, services, or organizational management. Its core criterion is to reduce environmental risks, pollution, and resource consumption while achieving equivalent functionality, i.e., focusing more on environmental performance than motivation. Paipa-Sanabria (2025) further summarizes this by arguing that any product, process, or organizational change that substantially reduces environmental risks and impacts relative to existing alternatives can be considered a broad form of ecological innovation or green technology.

Based on the aforementioned international organizations and academic literature, several common key points in the definition of green technology can be summarized: (1) In terms of goal orientation, green technology focuses on reducing environmental burden, improving resource utilization efficiency, and supporting low-carbon transformation; (2) In terms of scope, it includes not only specific equipment and processes, but also "soft technologies" such as management systems and business models, exhibiting systematic and full life-cycle characteristics; (3) In terms of relativity, it emphasizes "significant improvement" in environmental performance compared to traditional technologies. Accordingly, in this study, "green technology" can be defined as: at the level of products, processes, equipment, and related management systems, it can significantly reduce pollution emissions, resource consumption, and carbon footprint compared to existing alternatives, and support the green and low-carbon transformation of economic activities. This definition is not only in line with international mainstream norms, but also provides a conceptual basis for the measurement and empirical analysis of corporate green technology innovation in the following text.

Traditional technologies follow the logic of neoclassical economics, pursuing economic efficiency maximization as the sole objective and treating the environment as an “externality” that provides inexhaustible resources and serves as a sink for waste (Porter & van der Linde, 1995). In contrast, Gan Dejian et al. (2003) argue that green technologies emphasize a balance between economic development and ecological sustainability, fully leveraging human agency to promote economic growth while adhering to natural laws, thereby avoiding an imbalanced development model that prioritizes economic growth at the expense of environmental protection. Table 1 summarizes the main differences between green technologies and traditional technologies.

Table 1. *Differences between green technologies and traditional technologies*

	Green technology	**Traditional technology**
Environmental protection	Prioritize ecological benefits and are committed to reducing or eliminating pollution and damage to the environment.	Focusing on economic benefits may lead to pollution.
Innovation	It has a certain degree of innovation, but it may gradually become conservative and lack innovation over time.	It has a certain degree of innovation, but it may gradually become conservative and lack innovation over time.
Resource utilization	We should focus on the conservation and efficient use of natural resources.	Without deliberate control over the consumption of natural resources, resource utilization is low, which may lead to resource waste.
Long-term benefits	It is conducive to achieving sustainable development, improving the environment, and obtaining greater social benefits.	Focusing more on short-term economic benefits may lead to neglecting the negative impacts in the long run.

Source: Compiled by the author

(2) Green Technological Innovation

Early studies often viewed green technology innovation as a passive behavior by companies in response to environmental regulations. Jaffe et al. (1995) defined it as "the development of new technologies that can reduce the negative externalities of environmental pollution," clearly emphasizing environmental orientation but neglecting economic value. Fussler & James (1996) and Berry and Rondinelli (1998) further pointed out that green technology innovation is innovation implemented at the product or process level to reduce adverse environmental impacts. Companies often adopt such innovations to cope with increasingly stringent environmental regulations, and companies with advanced green technologies may also lobby for stricter environmental standards to consolidate their competitive advantage. Rennings (2000), Bernauer et al. (2007), and Kemp (2010), within the framework of "ecological innovation," summarized green technology innovation as innovative activities that, compared to existing solutions, can avoid or reduce environmental damage and improve environmental performance in terms of products, processes, technologies, and services, emphasizing results orientation while downplaying motivational distinctions. Schiederig et al. (2012) defined green (ecological) innovation as hardware and software innovation related to green products or green processes, with the common goal of reducing resource consumption and environmental burden. Based on this, Gao et al. (2022) and Huang (2025) further proposed that green technology innovation should be understood as a type of innovation activity that, under the premise of adhering to both ecological and economic norms, achieves efficient resource utilization, reduces pollution and carbon dioxide emissions, and minimizes total costs throughout the product's entire life cycle through technological and managerial innovation.

Based on the above definitions, "green technology innovation" can be summarized as follows: Green technology innovation generally refers to technological progress and creation with the core objectives of promoting sustainable development and improving environmental quality. This means using technological advancements to reduce energy consumption, reduce pollution emissions, improve resource utilization, and support ecological environmental protection. It is not limited to traditional environmental protection technologies but also includes innovations in areas such as clean energy, energy conservation and emission reduction, waste recycling and reuse, green manufacturing, and green building.

Compared to traditional technological solutions, green technology innovation has achieved significant improvements in environmental performance, encompassing both technological and institutional innovation activities. Within the framework of this study, this definition aligns with the mainstream international concept of "green innovation" and facilitates the quantitative measurement of green technology innovation activities at the level of Chinese listed companies through indicators such as green patents.

Based on the foregoing literature, the distinctions between green technologies and conventional technologies are summarized by the author, as presented in Table 2.

Table 2. *The difference between green technology and green technology innovation*

	Green technology	**Green technology innovation**
Core essence	Static results, products, and processes	Dynamic processes, activities, and capabilities
Nature	Existing technologies	New or significantly improved technologies

	Green technology	Green technology innovation
Key Points	Application and adoption of existing technologies	Creating and advancing new solutions
Role in sustainability	Implement existing solutions	Expanding and advancing the boundaries of solutions
Example	Solar panels, wind turbines	Transparent solar windows, high-efficiency battery recycling technology

Source: Compiled by the author

Green technologies primarily emphasize the application and diffusion of existing technologies to address environmental problems through practical implementation, whereas green technological innovation focuses on the creation of new technologies or the substantial improvement of existing ones in response to evolving environmental challenges and in support of sustainable development. Through technological advancement and the introduction of novel solutions, green technological innovation continuously expands the scope and efficiency of green technology applications.

A scientific classification of green technological innovation constitutes the foundation for accurately identifying its core characteristics and for measuring its level of development. Existing studies have constructed diversified classification systems from different perspectives, which can be broadly grouped into three main dimensions: classifications based on innovation content, environmental contribution, and the degree of innovation.

(1) According to the content of innovation, green technology innovation can be divided into two main types: product innovation and process innovation. Product innovation refers to the development of entirely new or significantly improved environmentally friendly end products, such as energy-saving home appliances, electric vehicles, and biodegradable materials (Rennings, 2000). Process innovation refers to the improvement of production methods, processes, and equipment to reduce resource consumption, waste emissions, and pollution levels during the production process, such as more efficient wastewater treatment technologies, energy recovery systems, or cleaner production processes (Kemp & Pearson, 2007).

(2) Based on the way technological innovation addresses environmental issues, green technology innovation can be divided into two main categories: end-of-pipe treatment technology and cleaner production technology. End-of-pipe treatment technology is a reactive

innovation that mainly focuses on treating pollutants already generated during the production process, such as installing flue gas desulfurization devices and wastewater treatment facilities (Hart & Dowell, 2011). Cleaner production technology, on the other hand, embodies the environmental management concept of prevention first, emphasizing avoiding or reducing pollutant generation at the source, such as using non-toxic raw materials and improving processes to increase resource utilization (Fussler & James, 1996).

(3) Based on the novelty and impact of technological innovation, green technology innovation can be divided into incremental innovation and breakthrough innovation. Incremental innovation is a continuous improvement on existing technological tracks, such as improving the fuel efficiency of traditional internal combustion engines and optimizing wastewater treatment process parameters. This type of innovation has lower risk and faster results, but its environmental improvement effect is relatively limited (Hockerts & Wüstenhagen, 2010). Breakthrough innovation refers to a technological paradigm shift that can fundamentally change the competitive landscape of an industry, such as entirely new renewable energy technologies and disruptive materials technologies. This type of innovation has higher uncertainty and risk, but once successful, it often brings revolutionary environmental improvement effects (Dosi, 1982).

1.1.2.3 Factors Affecting Green Technological Innovation

At present, academic research on the determinants of green technological innovation mainly focuses on two aspects. One strand of the literature examines the factors influencing firms' green technological innovation, while the other focuses on the effects of firms' internal characteristics on green technological innovation.

（1）External environment

① External policy environment

Among studies on the external policy environment, the most influential is the "Porter hypothesis" proposed by Porter and van der Linde (1995), which argues that well-designed environmental regulations can generate an "innovation compensation" effect by incentivizing innovation, partially or completely offsetting compliance costs and enhancing competitiveness. Empirical results from Jaffe and Palmer (1997) show that rising environmental compliance costs significantly increase corporate R&D spending, supporting a "weak version" of the Porter hypothesis. Ambec et al. (2013) further points out that strict and stable environmental policies can induce green innovation aimed at improving resource efficiency and processes.

Besides command-and-control regulations, market-based tools such as carbon taxes, emissions trading, and R&D subsidies are equally important. Popp (2002) found that energy prices and the intensity of environmental regulations are key factors driving the growth of patents for air pollution control technologies; Caliendo et al. (2022) demonstrate that R&D subsidies for clean technologies can effectively share the costs and risks of corporate innovation, significantly promoting breakthroughs in green technologies. Given the long-term and high-risk nature of green innovation, policy stability is particularly crucial, as policy uncertainty can significantly inhibit companies' willingness to engage in green R&D (Borghesi et al., 2015). Li et al. (2022) thus emphasize in their systematic review that environmental regulations, institutional pressures, and legitimacy pressures together constitute the core external institutional environment for corporate green technology innovation.

In recent years, green finance policies have also been incorporated as an important component of the external policy environment. Liu (2025), based on data from listed companies, found that green finance instruments such as green credit and green bonds can significantly increase corporate investment in green innovation and output of green patents by alleviating financing constraints and reducing capital costs. Ren (2025) further shows that green finance policies not only directly promote firms' green technological innovation, but also indirectly foster regional green technological progress by improving the green investment and financing environment at the city level.

② External market environment

The rise of green consumerism presents new market opportunities for businesses: when consumers prefer environmentally friendly products and are willing to pay a premium, businesses are motivated to respond through green innovation. Flammer (2013) demonstrates that consumer environmental awareness can translate into market pressure, prompting businesses to adopt more environmentally friendly products and technologies.

Meta-analysis of over 200 articles on corporate eco-innovation and multiple empirical reviews show that market demand, customer and supply chain pressures, cost-saving expectations, and competitive pressure are key external factors driving corporate green innovation, with their effects even stronger than some internal organizational variables (Zhiwei, 2025; Pereira, 2012; De Marchi, 2012). In fierce competition, if competitors gain market share or reputational advantage through green innovation, peers often form a "competition-follower" mechanism through imitation and catching up (De Marchi, 2012).

Meanwhile, the rise of ESG investment has made the capital market pay more attention to corporate environmental performance. Companies that perform well on environmental issues usually have higher future returns and valuations. This "hard constraint + soft incentive" further prompts management to attach importance to green technology innovation (Khan, Serafeim & Yoon, 2016).

(2) Internal environment

① Internal operating environment

Green technology innovation is typically characterized by high investment, high risk, and long payback periods, making internal resources and capabilities a key constraint. Studies by Kemp and Pearson (2007) and others have shown that sufficient internal funding and financial redundancy significantly increase the likelihood and intensity of green innovation, and companies with stronger profitability are better able to withstand the risk of failure in green R&D. Cohen and Levinthal (1990) pointed out that a company's existing knowledge base and technological capabilities determine its efficiency in absorbing new external knowledge, which is the core "absorption capacity" for achieving green innovation.

At the organizational level, Bossle et al. (2016) and several systematic reviews on green product innovation (2014; 2022) argue that incorporating environmental performance into incentive assessments, fostering a learning-oriented and fault-tolerant innovation culture, strengthening cross-functional collaboration and continuous R&D investment, and systematically tracking market and regulatory changes are key internal success factors for driving innovation in environmentally sustainable products and processes. A broader review of green innovation further points out that a clear green strategic positioning, a standardized environmental management system, green human resource management, and digital and knowledge management capabilities together constitute the core "organizational soil" supporting corporate green technology innovation (Huo, 2024; Rupasinghe, 2024).

② Top management characteristics

The top management team (TMT) serves as the core decision-making body of corporate strategy, and managers' personal characteristics, values, and cognitive frameworks directly shape firms' willingness to engage in and invest in green technological innovation. Prior studies show that managers' environmental responsibility awareness and green-oriented leadership significantly enhance both the propensity and performance of firms' green innovation activities (Cordano & Frieze, 2000; Chen & Chang, 2013).

From the perspective of human capital and behavioral traits, executives who are younger, highly educated, and possess scientific or R&D backgrounds are more inclined to embrace change, recognize technological trends, and appreciate the long-term value of green innovation, thereby showing a stronger tendency to increase green R&D investment (Bantel & Jackson, 1989; Amore et al., 2019). Moreover, appropriate equity-based incentives can better align managers' interests with firms' long-term development goals, encouraging them to bear the short-term risks associated with green technological innovation (Berchicci & King, 2007). Some studies further find that executives with a certain degree of overconfidence or hubris are more sensitive to environmental issues and more likely to proactively promote green innovation strategies and resource allocation (Arena et al., 2017).

1.1.2.4 Measurement of Green Technological Innovation

There is currently no consensus on the measurement of green technological innovation, with existing approaches mainly focusing on two dimensions: innovation inputs and innovation outputs.

Measures of innovation inputs primarily capture the various resources firms invest to achieve green technological innovation and serve as leading indicators of firms' innovation intentions and strategic orientation. Prior studies commonly regard environment-related R&D expenditure as a core variable for measuring green technological innovation, arguing that additional R&D investment driven by environmental concerns constitutes a key link between policy incentives and technological outcomes (Rennings & Rammer, 2009; Hamamoto, 2006). Beyond financial resources, green innovation also relies heavily on specialized technical personnel; accordingly, the literature incorporates the number and proportion of R&D personnel into input-based measurement frameworks (Popp & Newell, 2012).

In terms of specific operationalization, domestic studies often employ indicators such as the ratio of R&D investment to energy consumption, the share of R&D personnel, and the proportion of green R&D expenditure to characterize the intensity and structural features of green innovation inputs in industrial firms (Wang et al., 2018; Xu, 2019).

Measures of innovation outputs focus on the direct outcomes of innovative activities and constitute the core basis for evaluating the efficiency and value of green technological innovation. Owing to their objectivity and comparability, patent data have become the dominant indicator in international research. A large body of studies measures firms' green technological innovation using the number, share, and structural characteristics of green patents. For example, Acemoglu et al. (2012) use the proportion of green patents in total patents to capture the "green bias" of technological development, while Urbaniec (2021) examines the evolution of green technologies based on cross-country environmental-related patent data.

In the domestic literature, Qi Shaozhou et al. (2018), Wang Xin et al. (2021), and Yu Bo (2023) primarily employ the number and proportion of green patent applications or grants to measure green innovation output among listed firms. Chen Lifeng et al. (2023), drawing on the WIPO green patent classification, construct a more comprehensive output measurement framework by using the number of granted green patents to reflect innovation scale and forward citation counts to capture innovation quality, thereby forming an indicator system that integrates both the quantity and quality of green technological innovation outputs.

1.2 The Impact of Green Credit Policy on Firms' Green Technological Innovation

A synthesis of the literature on green credit policy and firms' green technological innovation indicates that no unified consensus has yet been reached regarding how green credit policy affects firms' green technological innovation. Existing studies suggest that the relationship between green credit and green technological innovation is relatively complex, with discussions mainly focusing on its potential dual effect: green credit policies may both promote and inhibit corporate green technology innovation activities.

1.2.1 Promoting Effects

Overall effects

Multiple studies have shown that green credit, as an important policy tool of green finance, significantly enhances enterprises' green technology innovation capabilities by reducing financing costs, alleviating funding constraints, and providing low-interest loans, thus promoting a shift from end-of-pipe treatment to source prevention (Junxiu Sun et al., 2019; Hong et al., 2021). Theoretically, green credit is largely consistent with environmental regulation in terms of its goals and effects, conforming to the "regulation-incentivized innovation" logic emphasized by Porter's hypothesis (Li Qingyuan, 2020).

Empirical evidence shows that after the implementation of green credit policies, agency costs in regulated industries declined significantly, providing firms with greater financial flexibility to support innovation (Wang Xin & Wang Ying, 2021). Studies by Hong et al. (2021), Hu et al. (2021), as well as Xiong (2023) and Shu Limin (2023), consistently find that following the implementation of the Green Credit Guidelines, firms in the treatment group experienced significant increases in both the quantity and quality of green patents, indicating that green credit directly promotes green technological innovation through differentiated credit allocation.

Taking China as an example, Li et al. (2021) found that green credit policies have a significant lagging effect on the efficiency of green innovation in heavily polluting industries; Gao et al. (2022), Yang Chao (2024) and Lin Lefen et al. (2024) further pointed out that while green credit compresses the financing space of high-energy-consuming and high-polluting enterprises and raises debt costs, it plays a dual role of "coercion-guidance" to force enterprises to accelerate green technology research and development and transformation and upgrading.

Related reviews indicate that green credit, by optimizing bank credit structures and guiding funds from energy-intensive and polluting industries to green industries, creates a financial ecosystem conducive to green technology innovation at the macro level. In practice, the "Green Revolving Loan" case disclosed by the International Institute of Green Finance at the Central University of Finance and Economics (2025) vividly demonstrates the direct role of green credit in reducing financing costs and supporting green technology innovation.

Indirect Effects

The existing literature generally agrees that the impact of green credit policy on firms' green technological innovation is not a single linear process, but rather operates indirectly through multiple mediating channels. The two most frequently examined mechanisms are (i) financing constraints and financing costs and (ii) environmental and R&D investment.

First, with respect to financing channels, a large body of research reveals the mechanism through a "green credit–financing constraints–innovation" pathway. Liu et al. (2019) and Xu and Li (2020) find that the Green Credit Guidelines increased debt financing costs and shortened debt maturities for highly polluting firms, thereby intensifying financing constraints, which laid the groundwork for incorporating financing constraints into subsequent mediation analyses. Empirical evidence from He et al. (2019) and Wang et al. (2022) shows that green credit significantly promotes green technological innovation by improving the financing environment for green firms and alleviating financing constraints, with the mediating effect being particularly pronounced for private and small- and medium-sized enterprises that originally faced more severe financing pressures. More recently, using data on Chinese listed firms from 2009 to 2022, He et al. (2025) further construct a mediation model of "green credit–financing constraints/financing costs–green innovation", confirming that green credit enhances environmental innovation output by easing financing constraints and reducing financing costs, and that firms' digital transformation strengthens this mediating chain.

Second, with respect to environmental and R&D investment, firms often reallocate the green credit they obtain or the financial costs they save toward their R&D departments, particularly to green technology R&D projects. A range of empirical and case-based studies show that green financial instruments can ease funding bottlenecks faced by green firms during technological upgrading and expansion, strengthen their willingness to invest in clean technologies and related R&D projects, and significantly increase the ratio of R&D expenditure to total assets among firms receiving green credit support. Moreover, a substantial share of newly added R&D investment flows into green patent output, indicating that R&D investment plays a key mediating role in the "credit resources–innovation output" chain (Falcone & Sica, 2019; Liu et al., 2021; Wang et al., 2022).

In the Chinese context, Xu et al. (2023) used the DID and mediation effect model to examine the "green credit-environmental investment-green innovation" chain and found that the "Green Credit Guidelines" significantly increased the environmental capital expenditure of heavily polluting enterprises, and that environmental investment had a significant partial mediating effect between green credit policies and green patents. Wang et al. (2022) further distinguished between green R&D and non-green R&D and found that green credit policies may not significantly increase the overall R&D expenditure of enterprises, but they significantly promoted the inclination of internal R&D funds of enterprises towards green technology fields.

1.2.2 Inhibiting Effects

While most studies agree that green credit policies are generally beneficial to enterprises' green technology innovation, some literature points out that their effectiveness is constrained by enterprise characteristics and policy design. First, over-reliance on government subsidies may weaken the "forcing" mechanism of green credit; when enterprises receive high levels of government subsidies, their willingness to innovate in green technology actually decreases (Zhang Xiao & Hu Jinyan, 2022). Simultaneously, policy implementation deviations and "greenwashing" behaviors can easily lead to a misallocation of credit resources, weakening the policy's effectiveness (IMF, 2020). Further empirical results show that green credit has a crowding-out effect on green innovation in some situations: Zhang Fang (2023) found that green innovation in A and B category enterprises was significantly inhibited; Yang Liuyong, Zhang Zeye (2021), and Liu Chuanjiang et al. (2022) pointed out that after the policy implementation, the credit scale of heavily polluting enterprises shrank, credit costs rose, and the overall green technology progress rate of the industry declined; Xu Baochang et al. (2023) argued that under the strengthening effect of financing constraints, green credit policies are not conducive to improving the quality of green innovation in heavily polluting enterprises, but instead induce "greenwashing" behavior.

Building upon the aforementioned research, several gaps remain that require further exploration. First, existing studies often use the number of green patents as a single indicator, lacking a distinction between the quantity and quality of green technology innovation. Second, at the theoretical level, existing research largely remains within a single theoretical perspective, lacking an integrated analytical framework that integrates sustainable development theory, the Porter hypothesis, financing constraints theory, and the resource-based perspective. Third, while existing literature has explored the impact of green credit from the perspectives of financing constraints and R&D investment, a systematic examination of its impact based on the level of environmental information disclosure is still lacking. Fourth, analysis of heterogeneity differences across different industries remains insufficient. Therefore, this study takes Chinese listed companies as its research object, systematically identifying the impact of green credit policies on corporate green technology innovation, and deeply analyzing its mechanisms and heterogeneity characteristics. This will help enrich existing theoretical and empirical research, providing stronger theoretical support and policy basis for optimizing my country's green credit policy design and improving corporate green technology innovation performance.

1.3 Theoretical Foundations and Research Hypothesis

1.3.1 Theoretical Foundations

This study constructs a theoretical framework based on an analysis of the relationship between green credit policy and corporate green technology innovation, aiming to provide practical suggestions for optimizing green credit policy and maximizing the achievements of green technology innovation. In this process, relevant theories are selected and integrated from two dimensions: green credit policy and corporate green technology innovation. Through a step-by-step analysis and comparison of these theories, the study gradually moves from the phenomenological level to the essential level, thereby revealing the intrinsic connection between the two. The logical relationship of the relevant theories is shown in Figure 1.

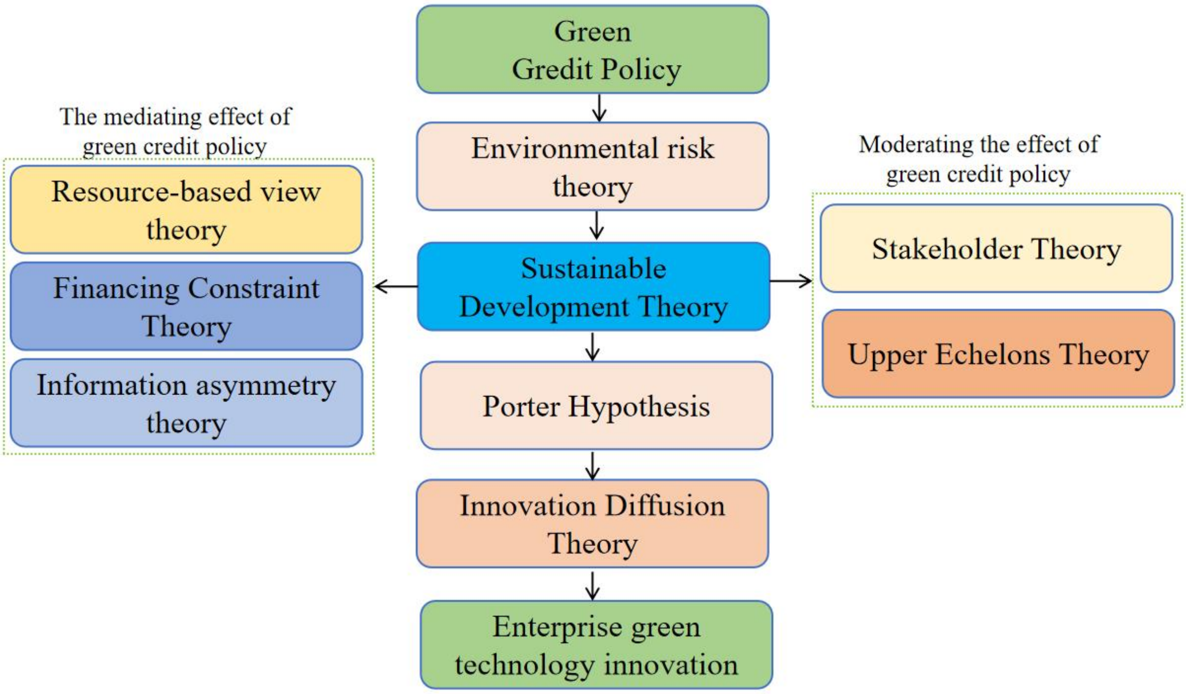


Figure 1. *Relationship between Theories*

Note: This diagram was created by the author based on previous research literature. (Stakeholder Theory)

The diagram above comprehensively illustrates the theoretical foundations upon which this research is based and their interrelationships. Based on the relevance of each theory to the research topic and existing literature, they can be divided into two parts: core theories and supporting theories. The core theory is sustainable development theory; supporting theories include environmental risk theory, Porter's hypothesis, resource-based view theory, financing constraints theory, stakeholder theory, upper echelons theory, and innovation diffusion theory. Based on this, the overall theoretical framework of this research is constructed.

1.3.1.1 Sustainable Development Theory

The concept of sustainable development was first proposed in the Brundtland Commission's report, “Our Common Future”, in 1987, and defined as "meeting the needs of the present without compromising the ability of future generations to meet their own needs."

In 1992, the United Nations convened the Conference on Environment and Development (Earth Summit) in Rio de Janeiro, Brazil, adopting the “Rio Declaration” and “Agenda 21”. The conference emphasized the importance of sustainable development, calling on countries to fully consider environmental carrying capacity, reduce pollution, protect ecosystems, promote the rational use of resources, and achieve coordinated economic, social, and environmental development while pursuing economic growth.

In 2015, the United Nations General Assembly adopted the 2030 Agenda for Sustainable Development, which set forth 17 Sustainable Development Goals (SDGs), emphasizing the need for a comprehensive approach to global issues and calling on governments, businesses, and all sectors of society to work together to achieve coordinated economic, social, and environmental development.

At the corporate level, sustainable development theory has further evolved into a "corporate sustainable development perspective," emphasizing that companies should not only pursue profit maximization but also assume environmental and social responsibilities, achieving synergistic improvement in economic, environmental, and social performance. From the perspective of microeconomic entities, companies that ignore environmental externalities may gain short-term benefits but will face long-term risks such as resource constraints, policy pressure, reputational damage, and competitive disadvantages in the market. Therefore, promoting green technology innovation has become an important path for companies to achieve sustainable competitive advantage.

The core logic of sustainable development theory lies in the fact that, against the backdrop of increasingly stringent resource constraints and rising environmental pressures, the traditional extensive development model is unsustainable, and the economic system must achieve sustainable growth through structural adjustments and a transformation of its development model. In this transformation process, technological innovation plays a crucial driving role, especially green technology innovation. By improving resource utilization efficiency, reducing pollution emission intensity, and minimizing environmental externalities, it achieves synergistic progress in economic growth and ecological protection. Therefore, within the framework of sustainable development theory, green technology innovation is considered a core path and important tool for achieving a "win-win" situation for both economic and environmental benefits.

This paper argues that green credit policies, through financial incentives, guide enterprises to invest more resources in green R&D activities, thereby promoting green technology innovation. This mechanism aligns with the logic of "technological progress driving green transformation" emphasized in sustainable development theory.

Based on sustainable development theory, the basic logical framework constructed in this paper is as follows: Guided by the sustainable development goal of coordinating economic development with ecological protection, the government, through the implementation of green credit policies, guides the optimal allocation of financial resources towards green and low-carbon sectors, thereby changing the financing environment and resource acquisition structure of enterprises. On this basis, with policy incentives and financial support, enterprises increase investment in green technology innovation, enhance their green innovation capabilities and environmental performance, ultimately promoting industrial upgrading and the transformation of economic development patterns, achieving a green economic transformation.

1.3.1.2 Porter Hypothesis

The Porter Hypothesis, proposed by Porter in 1991 and systematically elaborated by Porter and van der Linde in 1995, posits that well-designed environmental regulations do not necessarily harm firm competitiveness. On the contrary, appropriate environmental policies can stimulate technological innovation, and the resulting "innovation compensation" may partially or even completely offset the compliance costs incurred by firms to meet environmental requirements.

Jaffe and Plamer (1997) further categorized the Porter Hypothesis into three types based on the degree of impact of environmental regulations on firm innovation: the Narrow-PH, the Weak-PH, and the Strong-PH. The Narrow-PH emphasizes that flexible environmental policies are more effective in incentivizing firm innovation; the Weak-PH points out that environmental policies incentivize certain types of technological innovation, but their impact on firm performance is uncertain; and the Strong-PH argues that environmental policies not only promote firm innovation but also enhance firm competitiveness through innovation, thus balancing environmental and firm performance.

Porter's hypothesis posits that appropriate environmental regulations can stimulate corporate innovation and enhance competitiveness through an innovation compensation effect. Its core lies in explaining how regulatory tools can prompt companies to shift from passive compliance to proactive innovation. Green credit policies, as a typical incentive-based environmental regulatory tool, impose financing constraints on highly polluting companies through differentiated credit arrangements, while simultaneously providing preferential financing conditions for green technology companies, thereby altering companies' financing costs and resource allocation structures. This encourages companies to increase investment in green technology research and development, reduce long-term operating costs, improve energy efficiency, and decrease pollution control expenditures. This mechanism aligns closely with Porter's hypothesis, which proposes that environmental regulations promote technological innovation and enhance competitiveness.

1.3.1.3 Information Asymmetry Theory

The theoretical foundation of environmental risk theory can be traced back to the research on environmental externalities and risk uncertainty in environmental economics in the 1970s (e.g., Arrow, 1970; Freeman, 1984), and the subsequent development of corporate risk management theory (Bromiley et al., 2001). At the corporate level, environmental risk is generally defined as the risk of uncertain losses faced by enterprises due to factors such as environmental pollution, resource constraints, climate change, strengthened environmental regulations, and public oversight.

With the intensification of global climate change and the continuous strengthening of environmental regulations, environmental risk has gradually evolved from an "externality problem" to a "corporate strategic risk." Environmental risk theory therefore emphasizes:

(1) Environmental problems are uncertain and long-term;

(2) Environmental risks have a systematic impact on corporate operating performance, financing capabilities, and market reputation;

(3) Enterprises need to reduce their exposure to environmental risks through proactive strategic adjustments and technological innovation.

Based on environmental risk theory, this paper argues that against the backdrop of continuously strengthening environmental regulations and increasingly severe resource constraints, the environmental risks faced by enterprises have significantly increased. Green credit policies, by incorporating environmental performance into credit review and financing cost systems, strengthen the risk constraint mechanism for enterprises, making environmental risks explicitly expressed at the financial level. Under this institutional pressure, driven by risk aversion and the motivation for long-term stable development, enterprises tend to increase investment in green technology innovation to improve resource utilization efficiency and environmental governance capabilities, thereby reducing their exposure to environmental risks. Therefore, green credit policies are not only a financial tool for optimizing resource allocation, but also a risk adjustment mechanism that guides enterprise transformation and upgrading through risk constraints, while green technology innovation becomes a crucial path for enterprises to achieve risk mitigation and long-term stable development.

1.3.1.4 Resource-Based View (RBV) theory

The core ideas of the resource-based view (RBV) were first systematically articulated by Wernerfelt (1984) in “A Resource-Based View of the Firm.” He argued that firms should be analyzed from the perspective of resources rather than products, conceptualizing firms as bundles of heterogeneous resources, and introduced concepts such as “resource position barriers.” This work marked the beginning of the resource-based turn in the field of strategic management.

In the 1990s, Barney (1991) further developed the Resource-Based View (RBV) in his work "Firm Resources and Sustained Competitive Advantage," proposing that firm resources can become a source of sustained competitive advantage if they simultaneously possess the four attributes of value, rareness, imperfect imitability, and non-substitutability (VRIN). He categorized firm resources into types such as physical capital, human capital, and organizational capital, establishing the RBV as one of the mainstream theoretical frameworks for competitive advantage.

Subsequent studies, through review and reflection, further clarified the conceptual boundaries and empirical testing pathways of RBV, gradually moving it from a static explanation of "internal resources determine competitive advantage" to one integrated with theories such as the knowledge-based view and dynamic capabilities.

In the field of environment and sustainable development, Hart (1994, 1995) proposed the "Natural Resource-Based View" (NRBV) based on RBV, arguing that a firm's competitive advantage is increasingly built upon its unique ability to address environmental issues. He proposed three types of environmental strategies: pollution prevention, product lifecycle management, and sustainable development, emphasizing that environmentally relevant resources and capabilities (such as clean technologies, environmental management systems, and collaborative relationships with stakeholders) can become new sources of strategic resources.

Russo and Fouts (1997), based on an empirical study of 243 US companies, found a significant positive correlation between environmental performance and profitability, with this relationship being stronger in high-growth industries. They proposed the view that "better green performance leads to higher financial performance," supporting the proposition of "green competitive advantage" from an RBV perspective, indicating that environmental management and green innovation can be considered a valuable and difficult-to-imitate combination of resources.

Subsequently, numerous international studies, within the RBV/NRBV framework, have regarded green technology capabilities, environmental management systems, green organizational culture, and green human capital as key strategic resources capable of delivering both economic and environmental performance.

The resource-based view emphasizes that corporate innovation is essentially a process of resource input, capability accumulation, and value transformation. Technological innovation and green technology innovation, in particular, often require continuous R&D funding, technological knowledge reserves, management capabilities, and organizational coordination. Therefore, whether a company possesses a sufficient and high-quality resource base directly affects its innovation investment intensity, innovation implementation efficiency, and innovation output quality. In this sense, the resource-based perspective provides an important internal viewpoint for explaining corporate green technology innovation behavior.

The resource-based view argues that a company's competitive advantage stems from its ownership and control of heterogeneous resources, and its ability to effectively integrate and allocate these resources. Only resources possessing value, scarcity, difficulty in imitation, and irreplaceability can be transformed into a sustainable competitive advantage. Green technology innovation, as a high-investment, high-risk, and long-term innovation activity, is highly dependent on resources such as funding, knowledge, technology, and organizational capabilities. Green credit policies alter the resource base for companies engaging in green technology innovation by influencing the availability of financial resources, financing costs, and capital allocation efficiency. For enterprises that meet the requirements of green development, green credit policies help alleviate financing constraints, enhance R&D investment capabilities, and encourage them to allocate more resources to strategic activities such as green R&D and technological upgrading, thereby improving their level of green technology innovation. Therefore, the resource-based perspective can provide an important theoretical explanation for the impact of green credit policies on enterprises' green technology innovation.

1.3.1.5 Financing Constraint Theory

The financing constraint theory was first proposed by Myers and Maiuf in 1984. This theory arose from the underdeveloped and imperfect Western capital markets and the widespread information asymmetry in economic life. Myers and Maiuf argued that due to information asymmetry, a firm's internal financing costs are often lower than its external financing costs. When a firm's internal cash reserves are insufficient to meet its needs, it is forced to seek external financing at a higher cost; this phenomenon is known as a financing constraint. Classical research indicates that firms cannot always obtain funding from capital markets under ideal conditions, especially in R&D activities characterized by high uncertainty, high risk, and long payback periods, where financing constraints are particularly prominent (Fazzari et al., 1988; Myers & Majluf, 1984).

In the context of green technology innovation, financing constraints become even more prominent. On the one hand, green technology R&D typically involves new processes, new materials, and systemic technological upgrades, resulting in high R&D costs and a significant risk of failure. On the other hand, its environmental benefits have certain externalities, making it difficult to fully internalize them through market mechanisms in the short term, thus reducing financial institutions' willingness to finance green innovation projects. Against this backdrop, without targeted financial support, companies often tend to scale back or postpone green technology R&D activities.

Based on the theory of financing constraints, this paper argues that green credit policies, through institutional arrangements, alter the external financing environment faced by enterprises and are an important tool for alleviating financing constraints on green technology innovation. By providing enterprises with green and environmentally friendly projects with preferential credit conditions such as low-interest, long-term loans, green credit policies reduce their financing costs and thus alleviate their financing constraints. Conversely, for non-green enterprises with high pollution and high energy consumption, green credit policies implement stricter credit standards, imposing significant financing restrictions and investment barriers. This leads to a substantial reduction in the total debt financing of high-energy-consuming and high-polluting enterprises, and banks and other financial institutions significantly reduce their loan quotas to these enterprises, making it difficult for them to obtain sufficient funding to maintain operations. This differentiated credit policy aims to force non-green enterprises to transform and upgrade through market mechanisms, reducing pollution emissions and improving resource utilization efficiency.

1.3.1.6 Information Asymmetry Theory

Information asymmetry theory is a crucial theory in modern economics and finance, primarily used to explain the distortion of resource allocation caused by differences in the quantity and quality of information possessed by market participants. This theory posits that in economic activities, the parties involved in a transaction typically do not possess perfectly symmetrical information. The party with more information often holds an advantage, while the party with less information struggles to accurately identify the true quality, risk level, and future value of the trading partner. This can lead to adverse selection, moral hazard, and other problems, further reducing market efficiency.

The systematic exposition of information asymmetry theory began in the 1970s, and three economists, George A. Akerlof, A. Michael Spence, and Joseph E. Stiglitz, jointly received the 2001 Nobel Prize in Economics for their pioneering contributions to this field.

Akerlof (1970) proposed the "lemon market" theory, pointing out that due to information asymmetry between buyers and sellers, low-quality products may crowd out high-quality products, leading to market failure. Spence (1973) explained from a signaling perspective that the party with information advantage can alleviate the problem of information asymmetry by transmitting its own quality information to the market through certain signals. Stiglitz and Weiss (1981) introduced the theory of information asymmetry into the credit market, pointing out that due to information asymmetry, banks and enterprises find it difficult to accurately identify the risk type and project quality of borrowing enterprises. This leads to credit rationing, meaning that even if enterprises are willing to bear higher interest rates, they may not be able to obtain the financing they need.

Information asymmetry theory posits that differences in the quantity and quality of information possessed by market participants can lead to adverse selection, moral hazard, and distorted resource allocation. In corporate financing, management typically possesses a greater understanding of a company's operations, innovation capabilities, and project risks than external financial institutions. Furthermore, green technology innovation is characterized by high investment, high uncertainty, and long cycles, further exacerbating information asymmetry between financing parties. Green credit policies, by incorporating environmental information and green development performance into credit decision-making systems and strengthening environmental risk identification and differentiated credit standards, help improve financial institutions' ability to assess the quality of corporate green projects, mitigating information asymmetry between banks and companies. Simultaneously, green credit policies may also encourage companies to improve their environmental information disclosure, enhancing the transparency and credibility of green innovation activities, thereby improving financing conditions and promoting green technology innovation. Therefore, information asymmetry theory provides an important theoretical explanation for the impact of green credit policies on corporate green technology innovation.

1.3.1.7 Stakeholder Theory

Stakeholder theory is a crucial theory in the field of business management and corporate governance, primarily used to explain how companies coordinate and balance relationships between different stakeholders during the business decision-making process.

Stakeholder theory was proposed by American scholar Edward Freeman in his 1984 book, “Strategic Management: A Stakeholder Approach”(Freeman, R. E., 1984). In the book, Freeman argued that companies should not only focus on the interests of shareholders but also consider the interests of other stakeholders such as employees, customers, suppliers, government, and the community. Freeman's research pioneered an important area in modern business management, emphasizing the need for companies to balance the interests of all parties in the decision-making process to achieve long-term sustainable development.

In the context of environmental governance and green transformation, stakeholder theory provides an important explanation for corporate green technology innovation. Green technology innovation is not only a crucial way for companies to improve resource utilization efficiency, reduce pollution emissions, and enhance competitive advantage, but also an important means for companies to respond to government regulations, meet investors' green preferences, improve social recognition, and fulfill their environmental responsibilities. Therefore, corporate green technology innovation is essentially a strategic response to the green demands of diverse stakeholders.

Stakeholder theory argues that companies do not solely serve to maximize shareholder interests, but need to comprehensively respond to the demands of diverse stakeholders, including shareholders, creditors, the government, employees, customers, and the general public. Corporate behavior is driven not only by internal profit targets but also by external resource supply, institutional constraints, and social supervision. In the context of green transformation, governments, financial institutions, and the public are increasingly focused on corporate environmental responsibility and sustainable development capabilities. Green credit policies, by incorporating corporate environmental performance and green development capabilities into credit resource allocation standards, strengthen the constraints and incentives imposed by stakeholders such as governments and financial institutions on corporate green behavior. To obtain financing support, improve social recognition, and reduce environmental risks, companies are motivated to respond to the green demands of diverse stakeholders by increasing investment in green R&D and promoting green technology innovation. Therefore, stakeholder theory can provide an important theoretical explanation for the impact of green credit policies on corporate green technology innovation.

1.3.1.8 Innovation Diffusion Theory

The diffusion of innovation theory, systematically proposed by Everett M. Rogers, posits that the adoption of innovation does not occur synchronously but unfolds over time within a specific social system, gradually spreading through information transmission, demonstration effects, and imitation mechanisms (Rogers, 2003). Within this framework, firms' adoption of new technologies is a trade-off decision, primarily dependent on their comprehensive assessment of the relative advantages of the innovation, risks and uncertainties, technological complexity, and the degree of support from the external institutional environment.

In economic research, the diffusion of innovation theory further emphasizes that the speed and path of innovation diffusion are not only determined by technological characteristics but are also significantly influenced by institutional arrangements, market competition, and policy incentives. When the external environment can reduce innovation uncertainty or increase expected returns, firms are more likely to be the first to adopt new technologies, and through industry competition and demonstration effects, encourage other firms to follow suit, thus forming a diffusion process that gradually progresses from "pioneers" to "imitators" (Mansfield, 1961; Hall, 2004).

In corporate innovation research, the innovation diffusion theory emphasizes that technological innovation is not only the result of resource allocation within a single enterprise, but also a gradual diffusion process driven by the combined effects of policy environment, market signals, industry interaction, and demonstration effects. Especially in the context of green development, green technology innovation often has a strong knowledge spillover and demonstration effect. Once some enterprises gain access to financing, policy support, and market recognition through green innovation, other enterprises may accelerate their adoption of green innovation under competitive pressure and the motivation to imitate, thus forming a diffusion mechanism from point to surface.

The innovation diffusion theory posits that innovation does not occur simultaneously among all actors, but rather, through information dissemination, demonstration effects, and environmental incentives, it gradually expands from a few pioneers to a wider group over a certain period. Green credit policies, by embedding green standards into the credit resource allocation process, send clear green development signals to enterprises and provide financing incentives to those that align with green development principles, thereby prompting some enterprises to take the lead in green technology innovation. When these pioneering enterprises gain access to financing, improved environmental performance, and market recognition through green innovation, their successful experiences will drive more enterprises to adopt green innovation behaviors through demonstration effects, imitation effects, and information dissemination, further promoting the diffusion of green technology innovation among the enterprise community. Therefore, the innovation diffusion theory can provide an important dynamic explanation for the impact of green credit policies on corporate green technology innovation.

1.3.1.9 Upper Echelons Theory

The upper echelons theory, proposed by Hambrick and Mason (1984), is based on the premise that a firm's strategic choices and operational performance are largely external manifestations of the values, cognitive structures, and experiential backgrounds of its senior managers. Given that managers' psychological characteristics and decision-making preferences are difficult to observe directly, existing research typically uses observable characteristics of senior executives (such as educational background, professional experience, and expertise) as proxy variables for their cognition and preferences, thereby explaining systematic differences in strategic decision-making and resource allocation behavior within firms (Hambrick & Mason, 1984).

Subsequent research has further extended this theory, emphasizing that in environments characterized by high uncertainty and complex information, the influence of top managers' personal backgrounds on firm decision-making becomes particularly pronounced (Hambrick, 2007). When firms face new policy shocks or technological changes, executives' ability to interpret external policy signals, their risk preferences, and their professional judgment directly shape the intensity of firms' responses to policy interventions and the direction of strategic adjustment.

In the context of green technological innovation, upper echelons theory offers substantial explanatory power. Green technological innovation is typically characterized by high investment requirements, long development cycles, and considerable uncertainty, such that decision-making depends not only on firms' resource endowments but also critically on top managers' interpretation and judgment of the policy environment and financial instruments.

Drawing on upper echelons theory, this study argues that executives' financial backgrounds play an important moderating role in the relationship between green credit policy and firms' green technological innovation. Specifically, when the top management team possesses financial expertise, it is better able to understand and implement green credit policies, proactively engage with green financial resources, optimize financing structures, and effectively allocate obtained credit support to green technology R&D activities, thereby strengthening the promoting effect of green credit policy on firms' green technological innovation. In contrast, in firms where executives' financial backgrounds are relatively weak, the incentive effects of green credit policy may be partially attenuated due to limited understanding or heightened risk aversion.

To explain the complexity of the relationship between green credit policies and corporate green technology innovation, this paper draws on a multidisciplinary theoretical foundation. As shown in Table 3, the conceptual model constructed in this study integrates sustainable development theory, porter's hypothesis, environmental fringe theory, financing constraint theory, information asymmetry theory, resource-based view theory, upper echelon theory, innovation diffusion theory, and stakeholder theory. These theories provide explanations from different dimensions and complement each other within the overall framework.

Table 3. *Theoretical Basis and Contribution to This Study*

Theory	**Core Idea**	**Contribution to This Study**	**Relationship With other Theories**
Sustainable Development Theory	To achieve coordinated development of the economy, society and environment, emphasized that "technological progress drives green transformation".	Support **H1. H2, H3, and H4** by explaining institutional arrangements and resource allocation.	It provides an overall theoretical framework, supplemented by other theories.
Porter's Hypothesis	Reasonable environmental policies encourage corporate innovation, and the benefits of innovation can offset compliance costs, thereby enhancing competitiveness.	Support **H1**by explaining the regulatory role of environmental regulations.	It serves as an important theoretical support for the main theory.
Resource-Based Theory	Holds that a firm's competitive advantage stems from its unique resources and capabilities.	Support for **H2** is provided by explaining the mediating role of R&D investment.	This provides a micro-foundation for the theory of innovation diffusion.
Financing Constraint Theory	External financing costs for businesses are typically higher than internal financing costs, which limits their investment and innovation activities.	Support **H3** by explaining the mediating role of financing Constraint.	Information asymmetry is the root cause of financing constraints.
Information Asymmetry Theory	It primarily explores the issues of adverse selection and moral hazard caused by information asymmetry.	Support **H4** by explaining the mediating role of environmental information disclosure.	The theory of information asymmetry is the "cause" and "starting point" of financing constraints.
Stakeholder Theory	Businesses need to balance the interests of all parties to achieve sustainable development.	Support for **H5** by explaining the moderating role of institutional investor shareholding.	Stakeholder theory complements institutional theory.
Upper Echelons Theory	A company's strategic decisions and innovation behaviors largely reflect the cognitive characteristics and experience background of its senior managers.	Support for **H6** by explaining the moderating role of executive financial background.	Together with stakeholder theory, this explains how corporate governance influences strategic and innovation decisions.
Environmental risk theory	Businesses are affected by factors such as environmental	Green credit policies encourage companies to	Institutional theory emphasizes external

Theory	Core Idea	Contribution to This Study	Relationship With other Theories
	uncertainty and environmental regulations during their operations.	reduce risk exposure by strengthening environmental risk constraints and innovating with green technologies.	institutional pressure, while environmental risk theory focuses on the increased risks brought about by the strengthening of environmental regulations.
Innovation Diffusion Theory	Innovation diffusion is a gradual process influenced by information flows, heterogeneity among actors, and the institutional environment.	Green credit policy is essentially an institutional innovation diffusion tool, and its operational logic is highly consistent with innovation diffusion theory.	Together with other theories, it explains the mechanism by which green credit policies influence corporate green technology innovation.

Source: Compiled by the author

1.3.2 Research Framework and Research Hypotheses

1.3.2.1 Research Framework

Building on the preceding review of the literature on green credit policy and firms' green technological innovation, as well as the discussion of the mechanisms and theoretical foundations through which green credit policy influences green technological innovation, this section proposes the overall framework of the present study. It then analyzes the specific pathways through which green credit policy affects firms' green technological innovation. Finally, drawing on prior research, this section constructs the study's conceptual model and formulates the corresponding research hypotheses.

Integrating the above theoretical perspectives, this study develops the research framework shown in Figure 2 to elucidate the mechanisms through which green financial policies influence firms' green technological innovation. This framework provides a structured analytical approach for understanding the complex interactions between green credit policy and firms' green technological innovation, thereby offering valuable insights for both academic research and practical application.

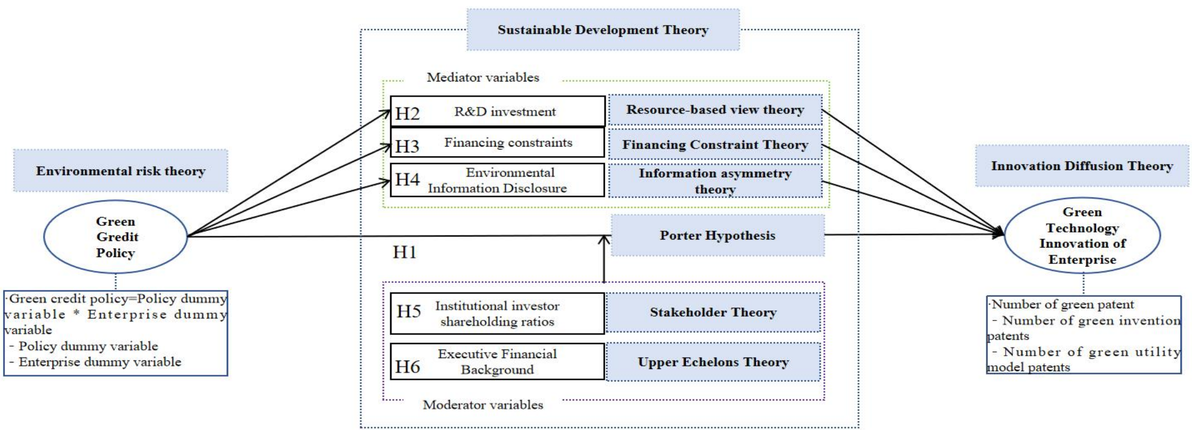


Figure 2. *Research Framework Diagram*

Note: This figure was derived by the author based on factors such as literature review, theoretical framework, research objectives, and variable relationships.

As illustrated in the research framework in Figure 2, the core variables of this study comprise seven key constructs. Firms' green technological innovation serves as the dependent variable, while green credit policy is the independent variable. R&D investment, financing constraints, and the level of environmental information disclosure are specified as mediating variables, and institutional ownership and executives' financial background are included as moderating variables. This study not only clarifies the mechanisms through which green credit policy affects firms' green technological innovation, but also provides a systematic set of research hypotheses for subsequent empirical testing.

1.3.2.2 Research Hypotheses

(1) Hypothesis on the overall effect of green credit policy on firms' green technological innovation

From a theoretical perspective, sustainable development theory posits that optimizing institutional arrangements and resource allocation methods is crucial for promoting the green transformation of the economy and society. Green credit policies embed sustainable development goals into the financial resource allocation mechanism, leveraging financial leverage to guide enterprises to invest more resources in areas such as energy conservation and emission reduction, pollution control, cleaner production, and green technology research and development. In this process, in order to adapt to the requirements of green development, obtain credit support and enhance long-term development capabilities, enterprises often attach greater importance to green technology innovation, thus forming green innovation behavior under policy incentives.Therefore, based on sustainable development theory, green credit policies, by optimizing financial resource allocation, strengthening green development orientation, and reducing financing constraints for green innovation, can effectively incentivize enterprises to increase investment in green technology research and development, thereby promoting the improvement of green technology innovation levels.

From an empirical perspective, an increasing number of studies directly examine the relationship between green credit policies and corporate green technology innovation. Green credit, by allocating funds to green and clean projects, can effectively enhance companies' willingness to innovate in green technologies and encourage them to increase their investment in green technology R&D (Wang Juanru et al., 2018; Shu Limin, 2023). For high-energy-consuming and high-polluting enterprises, the credit financing constraints created by green credit also have a significant "reverse forcing" effect, prompting them to accelerate green technology innovation and transformation and upgrading (Lin Lefen et al., 2024). Based on the above theoretical analysis and empirical research, this paper proposes the following research hypothesis:

H1: Green credit policy significantly promotes firms' green technological innovation.

(2) Hypotheses on the indirect effects of green credit policy on firms' green technological innovation

The mediating role of R&D investment

According to the resource-based view, R&D investment is a key resource for enterprises to gain a competitive advantage in green technology innovation. R&D investment is a core element driving enterprise technological innovation. In green technology innovation, the size of R&D investment directly determines whether an enterprise can successfully develop new technologies, products, and solutions. If an enterprise does not have sufficient funds for technological research, experimentation, and development, it will be difficult to achieve technological breakthroughs, thus affecting the efficiency and effectiveness of green technology innovation.

Green credit policies, by improving corporate financing conditions and alleviating financial constraints, provide enterprises with more disposable resources, thereby enhancing their R&D investment capabilities. With increased R&D investment, enterprises can invest more resources in green technology R&D, process improvement, and product innovation, thereby improving the level of green technology innovation. Therefore, R&D investment plays an intermediary role in this process; it is a bridge connecting funds supported by green credit policies to green technology innovation.

From an empirical perspective, "increased R&D investment" is one of the important channels through which green credit influences corporate behavior. Green credit not only significantly promotes green innovation in heavily polluting enterprises, but also corporate R&D investment plays a key mediating role between green credit and green innovation

(Si-gen, 2023). In the context of new energy enterprises, related research also shows that green credit improves corporate performance by supporting corporate R&D expenditure, and R&D investment has a significant mediating effect between green credit and corporate performance (Lee et al., 2024). Based on the above research, it can be considered that R&D investment is an important transmission path for green credit to affect corporate green technology innovation and operating performance. Based on the above theoretical analysis and empirical research, this paper proposes the following research hypothesis:

H2: Green credit policy promotes firms' green technological innovation by increasing firms' R&D investment.

The mediating role of financing constraints

The financing constraint theory posits that under conditions of information asymmetry and risk aversion, companies, especially those engaged in high-uncertainty, long-cycle R&D activities, often face limited external financing, thus inhibiting their innovation investment and efficiency. Green credit policies, by lowering the financing threshold for green projects and improving credit availability, help alleviate financing constraints for companies in green technology R&D, enabling them to allocate limited resources more effectively to high-quality R&D activities, thereby improving the efficiency of green technology innovation. Therefore, green credit policies can promote the improvement of green technology innovation efficiency among listed companies by alleviating financing constraints.

From an empirical perspective, a growing body of research has clearly demonstrated that the alleviation of financing constraints constitutes a key mediating mechanism through which green finance (green credit) promotes firms' green innovation. Ren (2022), using China's Green Finance Reform and Innovation Pilot Zones as the research context, finds that green finance policies significantly enhance firms' green technological innovation, with mechanism tests showing that easing financing constraints and increasing innovation investment are among the critical transmission channels. Similarly, Wang et al. (2022), based on data from Chinese A-share listed firms, confirm that green finance pilots significantly improve firms' green innovation performance by reducing financing constraints and optimizing the structure of capital supply, with financing constraints playing an important mediating role. Based on the above theoretical reasoning and empirical evidence, this study proposes the following hypothesis:

H3: Green credit policy promotes improvements in the green technological innovation efficiency of listed firms by alleviating financing constraints.

The mediating role of environmental information disclosure

Information asymmetry theory posits that significant information gaps exist between corporate management and external financial institutions regarding environmental risks, the quality of green projects, and innovation potential. The high uncertainty of green technology innovation further exacerbates this information asymmetry. Green credit policies, by incorporating environmental performance and information disclosure into the credit decision-making process, encourage companies to improve their environmental information disclosure levels, thereby enhancing external stakeholders' ability to identify a company's green development capabilities and environmental governance performance.

However, a company's ability to obtain green credit support often depends on its effective disclosure of environmental information, demonstrating the feasibility and effectiveness of its green technology innovations. Higher levels of environmental information disclosure reduce information asymmetry, increase corporate transparency, and thus enhance financial institutions' trust and support for its green projects, better promoting green technology innovation. Conversely, low levels of environmental information disclosure may weaken the effectiveness of green credit policies, as banks and investors cannot fully understand a company's environmental protection measures and technological innovation potential. In this process, environmental information disclosure plays a mediating role, connecting green credit policies and green technology innovation, driving the inflow of funds and the implementation of innovation.

Existing research provides preliminary evidence for the "green credit—environmental information disclosure—green technology innovation" chain. On the one hand, green finance instruments significantly improve the level of corporate environmental information disclosure. Geng et al. (2023) and Chen & Peng (2025) show that green credit policies significantly improve corporate (especially carbon emission) information disclosure and strengthen information transparency through reputation constraints and external pressure. On the other hand, environmental information disclosure has proven to be an important driver of green technology innovation. Grewal et al. (2019) point out that environmental information disclosure forms a "commitment mechanism" that can be externally monitored, prompting companies to fulfill their commitments with substantial green innovation. The empirical results of Lu & Li (2023) further confirm that environmental information disclosure has a significant positive impact on green innovation, and that digital transformation enhances this effect. Based on the above theoretical analysis and empirical research, this paper proposes the following research hypothesis:

H4: Green credit policy promotes firms' green technological innovation by enhancing the level of environmental information disclosure.

(3) Hypotheses on the moderating effects of green credit policy on firms' green technological innovation

The moderating role of institutional ownership

Stakeholder theory posits that corporate decision-making requires a comprehensive response to the demands of diverse stakeholders, including investors. Institutional investors, as significant external stakeholders, possess strong oversight and governance capabilities and a long-term value orientation, significantly influencing corporate strategic choices and resource allocation. Following the implementation of green credit policies, companies face stronger constraints and incentives for green financing. A higher proportion of institutional investor ownership strengthens their influence on management's short-term behavior and their support for green transformation strategies, thereby encouraging companies to translate policy incentives into green R&D investment and green technology innovation. Therefore, a higher proportion of institutional investor ownership amplifies the positive impact of green credit policies on corporate green technology innovation.

Numerous studies have demonstrated the crucial governance role of institutional investors in promoting corporate technological and green innovation. Aghion et al. (2013) found a significant correlation between increased institutional investor ownership, particularly among long-term oriented institutional investors, and improved corporate patent output. Existing research also indicates a significant positive correlation between institutional investor ownership and the level of corporate technological innovation (including green innovation) (Feng Genfu and Wen Jun, 2008; Zheng Shilin, 2021; Song Yu, 2023). From a corporate governance perspective, institutional investors are a vital force in improving corporate investment efficiency and reducing capital misallocation (Gillan & Starks, 2000). Therefore, in companies with higher institutional ownership, green credit funds are more likely to be effectively used for green technology innovation, thereby strengthening the positive relationship between green credit and green innovation. Based on this, this paper proposes the following research hypothesis:

H5: Institutional ownership positively moderates the relationship between green credit policy and firms' green technological innovation.

The moderating role of executives' financial background

Drawing on upper echelons theory, when a firm's top management team possesses financial expertise, it exhibits a stronger capacity to understand and implement green credit policies. Such executives are more likely to proactively engage with green financial resources, optimize the firm's financing structure, and effectively allocate obtained credit support to green technology R&D activities, thereby amplifying the positive effect of green credit policy on firms' green technological innovation.

In contrast, in firms where executives' financial backgrounds are relatively weak, the incentive effects of green credit policy may be partially attenuated due to limited understanding or greater risk aversion.

A substantial body of research indicates that executives' financial background is a critical characteristic shaping firms' financing conditions and resource allocation. Custódio et al. (2013) show that executives with financial expertise can significantly reduce firms' debt financing costs and extend debt maturity. Graham et al. (2013) further find that CFOs with experience in investment banking or commercial banking perform better in debt issuance and capital structure optimization. More recently, Guo and Zhao (2024) and Bai et al. (2025) demonstrate that such executives are more adept at building bank relationships and alleviating financing constraints, thereby providing more stable funding sources for long-term investments, including green innovation. When heavily polluting enterprises encounter green credit as a specific financing tool, the financial background of senior executives (especially the CFO) is expected to enhance the effectiveness of green credit in transforming green technology innovation. Based on the above analysis, the following research hypothesis is proposed:

H6: Executives' financial background positively moderates the promoting effect of green credit policy on green innovation in heavily polluting firms.

Based on the above analysis, this study proposes a total of six relational hypotheses, the summary of which is presented in Table 4.

Table 4. *Summary of Research Hypotheses*

Categories	Identifier	Hypothesis	Source
Direct action hypothesis	H1	Green credit policy can significantly promote green technology innovation in enterprises.	Cohen（2003）；Ambec, S.，（2002）；Zhang et al. (2021)
Mediating action hypothesis	H2	Green credit policy can promote corporate green technological innovation by boosting R&D investment intensity.	Lili Lian (2018) ；(；Si-gen,（ 2023) ； Lee et al.,（2024)
	H3	Green credit policy can improve the efficiency of green technology innovation in listed companies by alleviating financing constraints.	Li et al.（2021）； Ren（2022）; Wang et al.（2022）
	H4	Green credit policy can promote green technology innovation by improving companies' environmental information disclosure level.	Flammer（2021）; Grewal et al.（2019）； Eccles et al.（2014）
Moderating action hypothesis	H5	Institutional investor shareholding ratios positively moderate the relationship between green credit policy and corporate green technology innovation.	Aghion et al. (2013); Feng Genfu and Wen Jun (2008); Gillan & Starks,（2000)
	H6	Executives' financial background positively moderates the effect of green credit policies on promoting corporate green technology innovation.	Custódio et al. (2013); Graham et al. (2013); Guo & Zhao (2024)

Note: This table was drawn by the author

The research hypotheses in the table above summarize the hypotheses of the entire study. These include one direct effect hypothesis, namely that green credit can significantly promote corporate green technology innovation; three mediating effect hypotheses, which suggest that R&D investment, financing constraints, and the level of environmental information disclosure play a mediating role in the impact of green credit policies on corporate green technology innovation; and two moderating effect hypotheses, which suggest that the proportion of shares held by institutional investors and the financial background of senior executives can positively moderate the impact of green credit policies on corporate green technology innovation.

The Correspondence Between Research Questions, Hypotheses, and Theories

Based on the research hypotheses, theoretical foundations, and variable organization proposed in the previous section, the relationship between the research questions, hypotheses, theoretical foundations, and corresponding variables in this study is now organized into Table 5.

Table 5. *Correspondence between problems, hypotheses, and theories*

No.	question	Related theories	Hypothesis
1	Does green credit policy significantly promote both the quantity and quality of green technological innovation among Chinese listed firms?	1.Porter's Hypothesis 2.Institutional Theory	H1: Green credit can significantly promote green technology innovation in enterprises.
2	Do financing constraints, R&D investment, and environmental information disclosure play mediating roles in the relationship between green credit policy and corporate green technological innovation? Which pathways should be emphasized to enhance policy effectiveness?	1.Resource-based view theory	H2: Green credit can promote corporate green technological innovation by boosting R&D investment.
		1. Financing Constraint Theory	H3：Green credit can improve the efficiency of green technology innovation in listed companies by alleviating financing constraints.
		1.Information asymmetry theory	H4：Green credit can promote green technology innovation by improving companies' environmental information disclosure levels.
3	To what extent do institutional investor ownership and executives' financial backgrounds moderate the impact of green credit policy on corporate green technological innovation? Which moderating factors deserve particular attention?	1.Stakeholder Theory	H5 ： Institutional investor shareholding ratios positively moderate the relationship between green credit and corporate green technology innovation.
		1.Innovation Diffusion Theory	H6 ： Executives' financial background positively moderates the effect of green credit policies on promoting green innovation in heavily polluting enterprises.

Note: This table was compiled by the author based on relevant literature.

The table above details the correspondence between the research questions, theoretical foundations, and research hypotheses involved in this study: Hypothesis H1 corresponds to the first research question, hypotheses H2–H4 correspond to the second research question, and hypotheses H5–H16 correspond to the third research question. The specific theoretical foundations upon which each research hypothesis is based are detailed in the table above.

Summary Chapter 1

This chapter focuses on the core issue of "how green credit policies affect corporate green technology innovation," systematically outlining the conceptual connotation, influencing mechanisms, and theoretical foundations to provide a theoretical starting point and logical support for subsequent research.

First, it reviews the origin and definition of green credit; then it outlines the conceptual evolution, connotation, influencing factors, and commonly used measurement methods of green technology innovation, thus providing a basis for measuring the key variables in this study.

Secondly, focusing on the core issue of "the impact of green credit policies on corporate green technology innovation," this chapter reviews and summarizes existing literature from two aspects: overall effects and indirect mechanisms. On the one hand, most studies believe that green credit as a whole helps improve the level of corporate green technology innovation; on the other hand, relevant literature reveals that green credit plays a role through multiple mediating channels such as financing constraints, R&D investment, and environmental investment, exhibiting significant contextual and heterogeneous effects.

Finally, this paper uses sustainable development theory as the guiding theory, and incorporates institutional theory, environmental risk theory, information asymmetry theory, resource-based view theory, financing constraint theory, stakeholder theory, innovation diffusion theory, and upper echelon theory as foundational support to construct a comprehensive theoretical analysis framework of "green credit policy—corporate behavioral response—green technology innovation performance." This framework lays a solid theoretical foundation for the formulation of subsequent research hypotheses and the design of empirical models. Based on the above theoretical perspectives, this study constructs a research framework and, referring to previous research on relevant variables, proposes these six hypotheses. These hypotheses will be tested one by one in subsequent research.

CHAPTER 2. RESEARCH METHODOLOGY

Building upon the theoretical framework and research hypotheses established in the previous chapter regarding the impact of green credit policies on corporate green technology innovation, this chapter systematically elaborates on the methodology of this study. First, it explains the choice of research methods and uses an onion diagram as a mind map. Second, it introduces the specific research design and data collection plan. Finally, it clarifies the measurement methods for core variables and the construction of the empirical model, providing methodological support for subsequent empirical analysis.

2.1 Research Method Design

To systematically investigate the effects of green credit policy on firms' green technological innovation and the underlying transmission mechanisms, this study is grounded in positivism as its philosophical foundation and follows a deductive approach. In terms of methodology, a quantitative research paradigm is adopted. With respect to research strategy, the study integrates literature review, empirical analysis, and comparative analysis to address the research questions.

2.1.1 Research Philosophy

This study employs a positivist research philosophy. Positivism emphasizes basing research on objective facts and observable data, identifying regular relationships between variables through scientific methods, and revealing the causal relationships behind phenomena through statistical tests. Within this research paradigm, the validity of a theory relies on data evidence for falsification or support, and the summarization of patterns and the extraction of universal conclusions are achieved through induction and verification. This study uses quantitative analysis and statistical testing methods to analyze the impact, intensity, and transmission mechanism of green credit policies on corporate green technology innovation, which aligns with the basic requirements of the positivist framework.

2.1.2 Research Method

In terms of methodological approach, this study adopts a deductive method. Deduction emphasizes starting from established theories, formulating research hypotheses, and then verifying the validity of theories and hypotheses through systematic data analysis and empirical testing. It represents a top-down research paradigm, moving "from theory to data and from hypotheses to verification." This approach is particularly suitable for studies with clear theoretical foundations and quantifiable relationships among variables, as it facilitates the testing of causal relationships, the refinement of theoretical boundaries, and the empirical advancement of existing theories.

Based on sustainable development theory, Porter's hypothesis, information asymmetry theory, resource-based view theory, financing constraint theory, stakeholder theory, and innovation diffusion theory, this paper synthesizes previous research findings on relevant variables, constructs a research framework, and proposes six hypotheses. Based on this, econometric methods such as difference-in-differences models, mediation effect tests, moderating effect analysis, and heterogeneity grouping tests are used to systematically verify the hypotheses. Simultaneously, robustness tests and endogeneity handling ensure the credibility of the inferences. Finally, through a complete logical chain of "theoretical derivation → hypothesis formulation → empirical testing → mechanism identification → result verification," this study reveals the impact mechanism and boundaries of green credit in promoting corporate green technology innovation, providing reliable theoretical and empirical support for green finance policy evaluation and corporate innovation practices.

2.1.3 Method Selection

In terms of research methodology, this paper primarily employs quantitative research methods. Quantitative research is crucial and irreplaceable in fields such as social sciences, management, and economics. Based on quantifiable data, such as statistical data, questionnaires, and experimental results, it possesses objectivity and verifiability. Through statistical methods and data analysis software, data can be systematically processed and analyzed, leading to conclusions with universality and objectivity.

Therefore, this study constructs a core variable system based on large-scale panel data from listed companies, combined with green credit policies, green patent databases, and corporate financial data. Furthermore, it uses econometric models to empirically test the research hypotheses. This approach ensures the research process is carefully examined, resulting in more reliable conclusions.

2.1.4 Research Strategies and Time Horizon

2.1.4.1 Research Strategy

This study first reviews existing literature and relevant theories to extract the mechanism of action of green credit policies, constructs a theoretical framework, and proposes research hypotheses based on this framework. Second, using panel data of A-share listed companies in China, a difference-in-differences model is constructed for baseline regression, and mediating and moderating effect models are embedded to examine the overall impact, indirect impact, and moderating effect of green credit policies on corporate green technology innovation. Finally, heterogeneity analysis is used to further verify the research hypotheses. Third, heterogeneity analysis is used to further verify the research hypotheses. Finally, the data analysis results are summarized and discussed to form the main conclusions of this study. The specific research strategies used are as follows:

(1) Literature Analysis Method

Literature analysis is the fundamental method and logical starting point of this study, aiming to systematically review existing research and policy practices both domestically and internationally, providing theoretical basis and practical support for the construction of the research framework, the formulation of research hypotheses, the design of variables, and the explanation of mechanisms. This study focuses on two core themes: "green credit policy" and "enterprise green technology innovation." It employs multi-source collaborative analysis and cross-disciplinary comparison methods to conduct a systematic analysis from dimensions such as concept definition, theoretical foundation, impact mechanism, measurement methods, and research context.

In terms of literature selection, this study follows five principles: authority, cutting-edge research, systematicity, policy orientation, and research relevance. The academic literature mainly comes from authoritative domestic and international databases such as Web of Science, Scopus, Elsevier SDOL, Springer, CNKI, Wanfang, and VIP.

（2）Empirical Methods

Empirical analysis is the core methodology and foundation of this study. Based on objective data from listed companies in China, and through rigorous econometric models, it aims to conduct statistical inference and causal identification regarding the core question of "how green credit policies affect corporate green technology innovation."

First, a difference-in-differences (DID) model is constructed to test the statistical association between green credit policies and corporate green technology innovation, answering the core question of "whether it has an impact." Second, robustness tests such as the PSM-DID test and placebo test are used to verify the reliability of the baseline results. Third, a mediation effect model is used to identify the channels of influence of green credit, such as mechanisms like "easing of financing constraints" and "increased R&D investment," opening the transmission black box of "how it affects."

Next, a moderating effect model is used to analyze the extent to which institutional investor shareholding and senior management financial background moderate the impact of green credit policies on corporate green technology innovation.

Finally, based on theoretical expectations, grouped regression is conducted to test the differences in the effects of green credit under different corporate characteristics (such as ownership structure and company size), answering the question of "whose impact is more significant."

(3) Statistical Analysis Method The key data used in this paper, such as the number of green patent applications and basic financial indicators of listed companies, can be obtained through databases and professional platforms such as Wind, CSMAR, and the China National Research Data Service (CNRDS). After collecting and organizing the data measuring these main variables, a visualization method using charts was adopted to show the current development status of China's green credit policy and corporate green technology innovation, in order to more clearly reveal its development trends and characteristics.

(4) Comparative Analysis Method This paper mainly conducts comparisons from two aspects: first, it examines the current development status of green credit policy and corporate green technology innovation, and analyzes and compares their development characteristics at the regional and corporate levels; second, at the corporate level, it further compares the heterogeneity characteristics of different property rights, enterprise size, pollution attributes, and patent types, and at the regional level, it examines and compares the differences in spatial spillover effects between the eastern, central, and western regions.

2.1.4.2 Time Horizon

This study employs a longitudinal tracking design and analysis. Given that the "Green

Credit Guidelines" issued by the former China Banking Regulatory Commission in 2012 are considered a guiding document for the development of green credit in China, and that green credit has been effectively promoted and practiced in banking financial institutions since then, this study selects 2006-2024 as the research period. This period covers the stages before and after the issuance of the 2012 "Green Credit Guidelines," which helps to observe the long-term effects of green finance policies on corporate innovation behavior and the differences before and after the policy. In summary, the methodology used in this study is illustrated below:

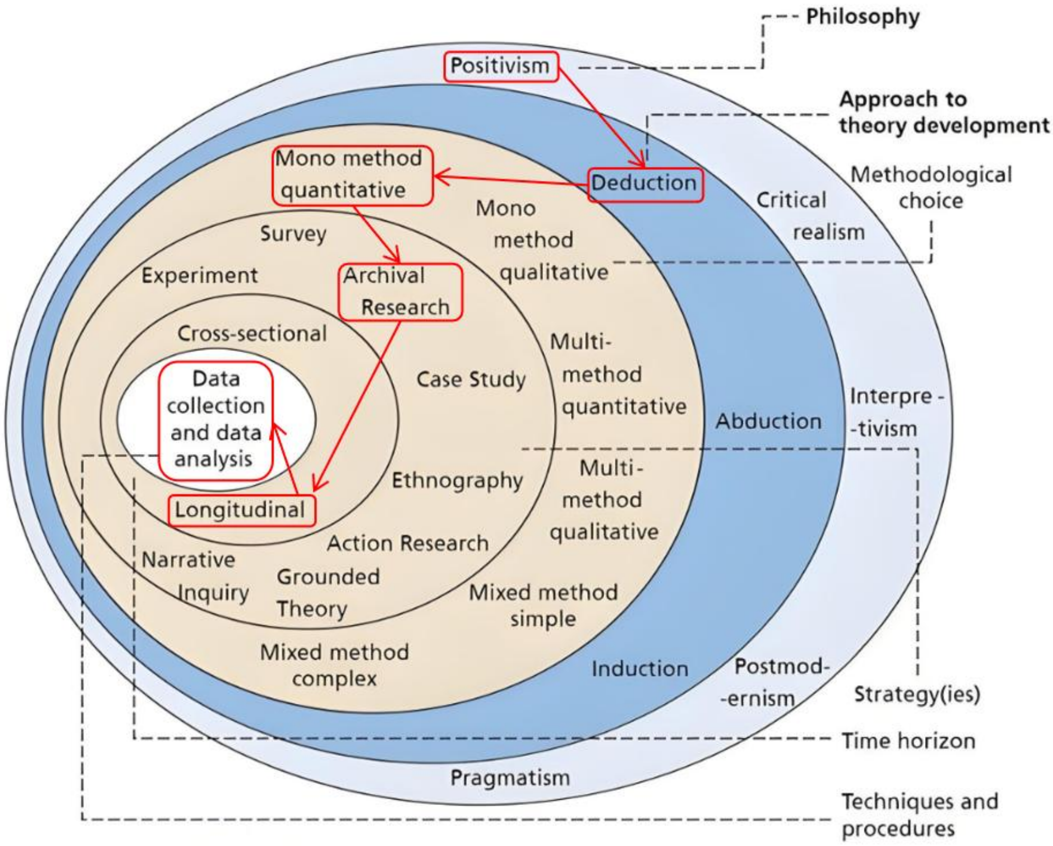


Figure 3. *The research methodology*

Note:This figure was drawn by the author based on the research "onion" figure and according to the methodology of this study.

Figure 3 illustrates the methodological framework of this study. Following the research onion model proposed by Saunders (2007), the study is designed across five dimensions. At the level of research philosophy, a positivist stance is adopted, emphasizing the testing of theoretical hypotheses using objective data to uncover relationships among variables and identify causal effects. At the level of research approach, a deductive pathway is followed, whereby research hypotheses are developed based on relevant theories and subsequently tested and validated using econometric models. In terms of research strategy, the study primarily employs an archival research strategy, utilizing publicly disclosed data from listed companies for empirical analysis. With respect to research methods, a quantitative research paradigm is adopted, relying on econometric techniques to identify causal relationships.Regarding the time horizon, a longitudinal research design is employed, based on panel data from Chinese A-share listed firms covering the period 2006–2023. In terms of data processing and analytical techniques, the study integrates a range of quantitative methods, including the difference-in-differences (DID) model, robustness and endogeneity tests, mediation and moderation models, and heterogeneity analyses.

2.3 Research Design

This study aims to systematically analyze the mechanism by which green credit policies influence corporate green technology innovation, and proposes countermeasures and suggestions to further promote corporate green technology innovation through green credit policies. The full structure of the paper is as follows:

The introduction introduces the research background, problem statement, research purpose and objectives, research significance and innovative points, and reflects on the limitations of the research.

Chapter One reviews and summarizes relevant literature on green credit policies, corporate green technology innovation, and the impact of green credit policies on corporate green technology innovation. It outlines the conclusions and development trends of existing research and provides a summary and evaluation of existing findings. Based on this, the theoretical framework of this study is presented, including sustainable development theory, Porter's hypothesis, financing constraint theory, information asymmetry theory, resource-based view theory, environmental risk theory, innovation diffusion theory, and stakeholder theory. Finally, by comprehensively applying these theories, this paper proposes six clear research hypotheses and constructs a clear research framework.

Chapter Two employs quantitative research methods. The quantitative research section utilizes data from CNRDS, CSMAR, Wind databases, and listed company annual reports. Using corporate green technology innovation as the dependent variable and green credit policy as the independent variable, it constructs a difference-in-differences model, a mediation effect model, and a moderating effect model.

Chapter Three presents the empirical analysis. Based on the aforementioned data and research methods, this chapter uses the difference-in-differences model, the mediation effect model, and the moderating effect model to test the research hypotheses and conduct heterogeneity analysis. On this basis, it proposes policy recommendations for improving green credit policies and promoting corporate green technology innovation from three dimensions: policy level, banking level, and environmental protection enterprise level. The overall research design of this paper is shown in Figure 4.

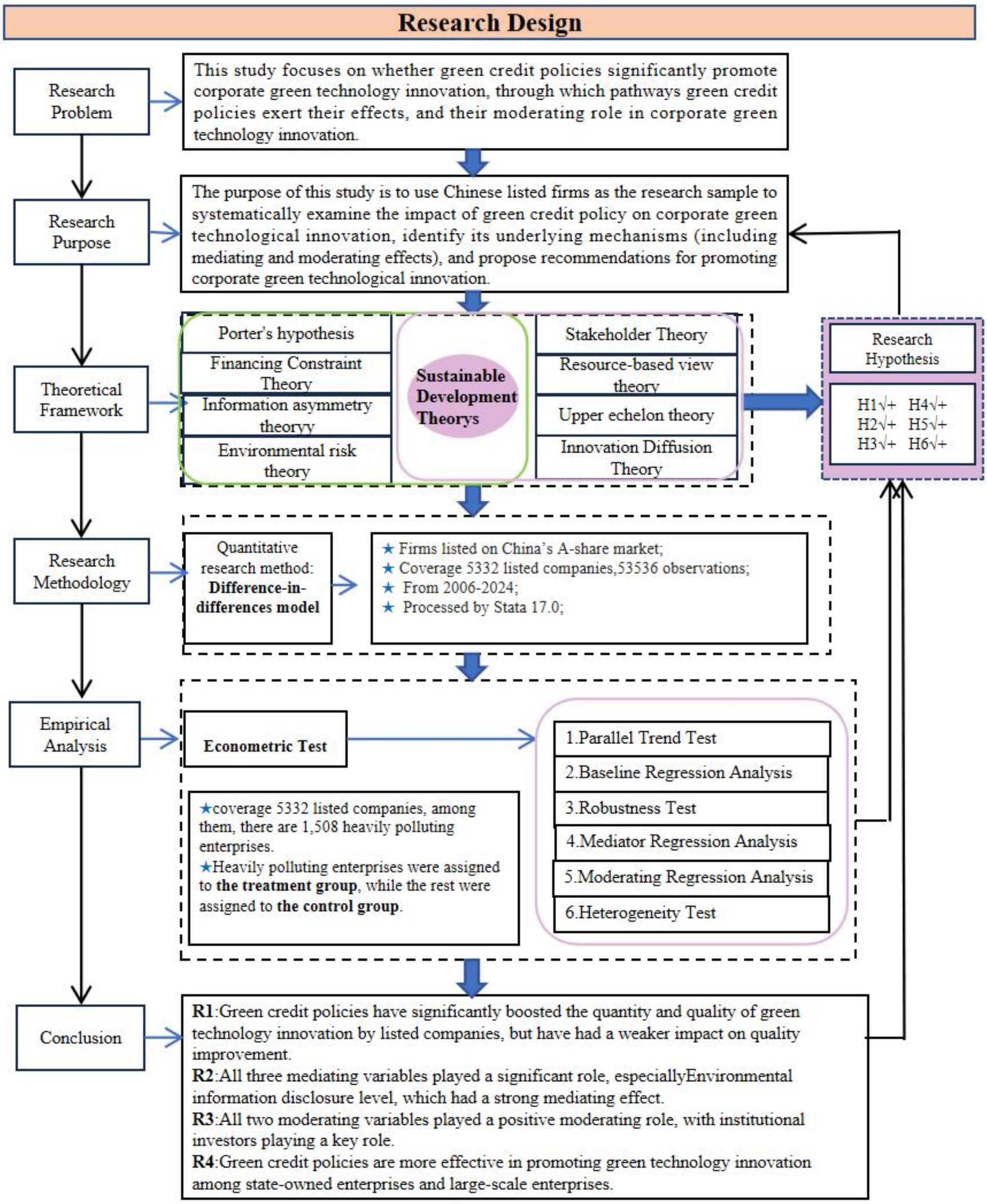


Figure 4. *Research Design*

Source: Drawn independently, based on the research framework of this thesis

2.3 Data Collection

This study aims to assess the policy effect of the 2012 Green Credit Guidelines on green innovation activities of heavily polluting enterprises in my country. The initial sample consisted of A-share listed companies in Shanghai and Shenzhen from 2006 to 2024. To ensure the accuracy of the data and the validity of the study, the initial sample underwent the following screening: (1) excluding listed companies in the financial and real estate sectors; (2) excluding companies with abnormal financial conditions such as ST, *ST, and PT companies; (3) excluding samples that were listed or delisted during the study period, resulting in significant data gaps; and (4) excluding samples with missing values for key variables (such as assets, liabilities, and R&D investment). After the above processing, a sample of 5,332 listed companies was obtained, including 1,508 heavily polluting enterprises, totaling 53,536 sample observations.

The main reasons for selecting listed firms as the research sample are as follows:

First, the reliability and continuity of data. Listed companies must comply with stringent financial and information disclosure requirements, regularly reporting their financial condition, operations, and environmental, social, and governance (ESG) data to the public and regulatory bodies. Compared to non-listed companies, listed companies have more comprehensive, reliable, and long-term environmental and financial data.

Second, sensitivity to policy impacts. Listed companies typically have significant advantages in terms of size, capital, and financing capabilities, and are more directly affected by government policies and financial market regulations. Because listed companies are required to comply with strict financial and information disclosure regulations and rely on capital market financing, their business practices and green technology innovations are more susceptible to the direct impact of policy changes. Therefore, the green technology innovation activities of listed companies can effectively reflect the effects of policy implementation.

Third, the representativeness of the sample. Chinese listed companies are widely distributed across various industries and regions, covering enterprises of different types, sizes, and sectors, providing a more heterogeneous sample for the research. This helps to analyze the impact of green credit policies more comprehensively and accurately. Unlisted companies, on the other hand, often have higher industry concentration or smaller sample sizes, making effective comparisons difficult.

The data sources for the indicators used in this paper mainly include the following categories: dependent and independent variables are from the China Research Data Service Platform (CNRDS); among the mediating variables, the financing constraint SA index is from the China Securities Market and Accounting Research Database (CSMAR), and the moderating variables are from the "China Statistical Yearbook", "China Industrial Statistical Yearbook", "China Energy Statistical Yearbook", "China Environmental Yearbook", and the official website of the Ministry of Ecology and Environment. Control variable data are from CNRDS, CSMAR databases, and listed company annual reports.

2.4 Variable Selection and Model Construction

2.4.1 Variable Selection

1. Dependent variable

This study measures firms' innovation behavior based on innovation output. Following Liu Qiang et al. (2020), the number of green patent applications is used to measure firms' green technological innovation output (Patent_total). More specifically, the number of green invention patent applications is employed to capture substantive green technological innovation (Patent_inv), while the number of green utility model patent applications is used to measure strategic green technological innovation (Patent_noninv). To avoid the loss of observations and to ensure the accuracy and comparability of the data, one is added to each patent count and the natural logarithm is taken before conducting further empirical analysis.

1. Independent variable

The core explanatory variable in this study is the interaction term of a difference-in-differences (DID) model constructed based on the quasi-natural experiment provided by the Green Credit Guidelines. This variable is defined as the interaction between a treatment group dummy (Treat) and a post-policy period dummy (Post), denoted as DID.

The treatment group dummy (Treat) is defined according to the 16 heavily polluting industries explicitly identified in the Guidelines on Environmental Information Disclosure for Listed Companies issued by the former Ministry of Environmental Protection in 2010. These industries include thermal power generation, steel, cement, electrolytic aluminum, coal, metallurgy, chemicals, petrochemicals, building materials, papermaking, brewing, pharmaceuticals, fermentation, textiles, leather processing, and mining. Firms operating in any of these 16 industries are regarded as being exposed to the policy shock and are assigned Treat = 1; firms in other industries constitute the control group and are assigned Treat = 0.

The post-policy period dummy (Post) is defined based on the official issuance of the Green Credit Guidelines in 2012. The years 2012 and thereafter are defined as the policy implementation period, with Post = 1, while years prior to 2012 are assigned Post = 0.

2. Mediating Variables

(1) R&D Investment. Dai Xiaoyong (2013) argues that the ratio of R&D investment to operating revenue reflects the level of R&D input corresponding to a given level of firm revenue. The ratio of R&D expenditure to operating revenue captures the share of R&D investment in a firm's overall scale of economic activity, thereby revealing how resources are allocated toward technological innovation and green technology development. A higher ratio indicates that a larger proportion of operating revenue is devoted to R&D, suggesting that the firm places greater emphasis on technological innovation, particularly green technological innovation. By comparing the ratio of R&D expenditure to operating revenue across industries or firms, it becomes possible to more clearly identify which firms allocate more resources to technological R&D, facilitating comparability among firms of different sizes. Accordingly, this study measures R&D investment using the ratio of R&D expenditure to operating revenue, defined as R&D investment intensity (RDR) = R&D expenditure / operating revenue.

(2) Financing Constraints. At present, the academic literature primarily adopts two approaches to measuring financing constraints: single-variable indices and multi-variable indices. Commonly used measures include the KZ index (constructed using indicators such as dividend payments and Tobin's Q), the WW index (which extends the KZ index by incorporating cash flow and leverage), and the SA index, which was developed by Hadlock et al. (2011) based on firm size and firm age. To mitigate potential endogeneity concerns, this study employs the SA index to measure firms' financing constraints. The specific formula is as follows:

$$SA = -0.737 * Size + 0.043 * Size^2 - 0.04 * Age$$

In this formula, Size denotes the natural logarithm of a firm's total assets (measured in millions), and Age represents firm age. The values calculated using this method are all negative. Ju Xiaosheng et al. (2013) argue that a larger absolute value of the SA index indicates a higher degree of financing constraints, thereby more clearly capturing firms' actual financing conditions. To facilitate interpretation, this study uses the absolute value of the SA index in the analysis.

（3） Environmental Information Disclosure Level. Corporate information disclosure constitutes an important channel through which stakeholders and institutional investors obtain knowledge about firms' operating conditions, while environmental information disclosure focuses specifically on the public reporting of firms' environmental practices. Such disclosure helps mitigate environmental information asymmetry and facilitates firms' access to external investment support. Following Wiseman (1982) and Kong Dongmin (2021), for non-monetary information (i.e., information that is difficult or impossible to quantify financially), a score of 2 is assigned if the information is disclosed and 0 if it is not disclosed. For monetary information (i.e., information that can be quantified financially), a score of 2 is assigned if the disclosure combines quantitative and qualitative information, 1 if only qualitative disclosure is provided, and 0 if the information is not disclosed. The detailed scoring criteria are presented in Table 6. In total, 25 indicators across five categories are aggregated, and the natural logarithm of the summed score is taken. The resulting value serves as a composite index measuring the level of firms' environmental information disclosure.

Table 6. *Scoring Rules for Corporate Environmental Information Disclosure*

	Disclosure type	**Disclosure content**	**Scoring Criteria**
Non-monetized information	Environmental management	Environmental protection concept Environmental protection goals Environmental regulatory system Environmental education and training Environmental protection special governance action Environmental incident emergency measures Environmental honors and awards "Three Simultaneities" System	Disclosure: 2 points; Undisclosed: 0 points
	Environmental certification	SO14001 Certification ISO9001 certification	
	Environmental information disclosure platform	Annual reports of listed companies Social Responsibility Report Environmental Report	
Monetization	Environmental	Wastewater discharge	Quantitative +

	Disclosure type	Disclosure content	Scoring Criteria
information	debt	COD emissions SO2 emissions CO2 emissions Smoke and dust emissions Industrial solid waste emissions Wastewater Reduction Waste gas emission reduction	Qualitative: 2 points; Qualitative only: 1 point; Not disclosed: 0 points.
	Environmental performance and governance	Dust and fume control Solid waste utilization Noise, light pollution, radiation control, etc. Clean production status	

Source: Synthesized by the author

4. Moderating Variables

(1) Institutional Investor Shareholding. Following Liang Shangkun (2018), the proportion of institutional investor shareholding reflects the strength of institutional investors as an external corporate governance mechanism. Specifically, institutional investor shareholding is measured as the ratio of the number of shares held by institutional investors at year-end to the total number of shares outstanding. This ratio captures the role and influence of institutional investors in corporate governance and serves as an indicator of their control and decision-making power. A higher level of institutional investor shareholding implies greater voting power and influence in corporate decisions, which may exert a positive effect on the promotion of green technological innovation, as institutional investors are more likely to support firms that align with sustainability objectives and green innovation strategies.

(2) Executive Financial Background. The personal information files of corporate executives are matched with detailed data on the educational backgrounds of directors, supervisors and senior executives to determine whether the executives have a financial background. The following criteria are used to assign values to them: if the executive's educational background includes professional terms such as "finance", "economics", "business administration", "accounting", "finance", "accounting" or "finance", or if they have work experience in the financial industry such as banking, securities, funds, insurance, trust, futures, asset management, etc., then the value is assigned as 1, indicating that they have a financial background; otherwise, if none of the above conditions are met, the value is assigned as 0, indicating that they do not have a financial background.

5. Control Variables

Drawing on the existing literature, this study also incorporates several control variables that may influence the relationship between green credit and firms' green technological innovation.

（1）Firm Size. In general, larger firms tend to possess more abundant resources, capital, and accumulated technological capabilities, enabling them to engage in more extensive green technological innovation. Given the substantial variation in firm size within the Chinese context, controlling for firm size helps isolate its potential impact on innovation activities and ensures that the empirical results more accurately capture the effect of green credit policy.

（2）Leverage Ratio. The leverage ratio provides an effective measure of a firm's capital structure, reflecting its financing composition. A higher level of leverage may affect a firm's financing capacity and risk tolerance, thereby influencing its investment in and development of green technological innovation. Controlling for the leverage ratio helps mitigate its potential confounding effect on green technological innovation, allowing the analysis to focus on the actual impact of green credit policy. In this study, leverage is measured as the ratio of total liabilities to total assets.

（3）Return on Total Assets (ROA). ROA reflects a firm's profitability and efficiency in asset utilization. Firms with stronger profitability are more likely to invest in green technological innovation, as they possess greater financial resources to support R&D activities. Controlling for ROA helps eliminate the influence of profitability on green technological innovation and ensures that the results primarily capture the effect of green credit policy. ROA is calculated as net profit divided by average total assets.

（4）Listing Age. Listing age reflects a firm's market experience and operational maturity. In general, firms that have been listed for a longer period tend to have accumulated more resources and experience in technological innovation and R&D, and are usually better able to access capital market support with more diversified financing channels. In contrast, recently listed firms may face greater financing constraints, which can limit their green technological innovation activities. Controlling for listing age helps eliminate this potential confounding effect. Listing age is typically measured as the observation year minus the listing year plus one, and the natural logarithm is taken.

（5）Revenue Growth Rate. The revenue growth rate reflects a firm’s growth potential and market expansion capacity. A higher revenue growth rate usually indicates rapid firm growth and suggests that the firm may possess more resources to support green technological innovation. Controlling for revenue growth helps mitigate the influence of firm growth on green innovation, allowing the analysis to focus more directly on the effect of green credit policy. In this study, the revenue growth rate is measured as the increase in operating revenue divided by operating revenue at the beginning of the period.

（6）Shareholding concentration. Major shareholders typically possess greater decision-making power and can influence firms’ green R&D and innovation decisions, thereby affecting green innovation outcomes. Accordingly, this study measures shareholding concentration as the shareholding of the largest shareholder divided by total shares outstanding.

Table 7. *Main variable definitions*

Variable type	Variable name	Variable symbol	Variable measurement
Dependent variable	Green Technology Innovation	Patent_total	Ln (Number of green patent applications + 1)
	Substantial Green Technology Innovation	Patent_inv	Ln (Number of green invention patent applications + 1)
	Strategic Green Technology Innovation	Patent_noninv	Ln (Number of green utility patent model applications + 1)
Independent variable	Policy Dummy Variable	Post	Years from 2012 onwards are assigned a value of 1, and years before 2012 are assigned a value of 0.
	Enterprise Dummy Variable	Treat	Heavily polluting enterprises are assigned a value of 1, while non-heavily polluting enterprises are assigned a value of 0.
	Green Credit Policy	Post*Treat	Policy dummy variable * Enterprise dummy variable
Mediator variables	R&D investment	RD rate	R&D investment as a percentage of operating revenue
	Financing constraints	FC	$-0.737 * Size + 0.043 * Size^2 - 0.04 * Age$
Moderator variables	Environmental Information Disclosure level	EIDL	Environmental Information Disclosure Score
	Institutional Investor Shareholding	Lis	Institutional investor holdings / total number of company shares
	Executive Financial Background	FinBack	If directors, supervisors, or senior executives have a financial background, the value is 1; otherwise, it is 0.
Control variables	Return on Total Assets	ROA	Net profit / average total assets.
	Firm Size	Size	Ln (Total Assets at Year-End)
	Listing Age	ListAge	The observation year minus the listing year plus 1 is sometimes used, and the logarithm is taken.
	Leverage Ratio	Lev	Total Liabilities / Total Assets
	Revenue Growth Rate	Growth	Revenue growth / Beginning revenue
	Shareholding concentration	Top1_Share	Shareholding ratio of the largest shareholder

Source: Synthesized by the author

2.4.2 Model Construction

2.4.2.1 Difference-in-differences model

The difference-in-differences (DID) model has distinctive advantages in the evaluation of policy effects. By treating a policy intervention as an exogenous shock within a quasi-natural experiment framework, the research sample is divided into a treatment group affected by the policy and a control group not subject to the policy intervention. The net effect of the policy on the outcome of interest is then identified by comparing the differences in outcomes between the two groups before and after the policy shock.

The core idea of the DID approach lies in identifying the average treatment effect of a policy by comparing the differential changes experienced by the treatment group and the control group before and after policy implementation (Si Lijuan & Cao Wuyu, 2022). Accordingly, the key to applying this method in the present study is the appropriate construction of the policy treatment group and the control group.

The green credit policy requires that firms' records of environmental violations be incorporated into the credit reporting system of the People's Bank of China, on the basis of which banking and financial institutions restrict or suspend the provision of new credit to the firms concerned. This policy exerts a relatively strong negative shock on the financing activities of heavily polluting enterprises with more severe environmental problems, thereby affecting their technological innovation behavior. By contrast, the impact on firms in non–heavily polluting industries is relatively weaker.

Based on the China Securities Regulatory Commission's "Guidelines for Industry Classification of Listed Companies," and according to the differences in the intensity of the policy's impact on different industries, listed companies in heavily polluting industries that are more affected by the policy are divided into a treatment group, while other listed companies that are less affected are divided into a control group (Yu Bo, 2021). Therefore, this paper uses listed heavily polluting companies as the treatment group and other listed companies as the control group.

The Difference-in-Differences (DID) model, by introducing individual and year fixed effects, can control for all time-invariant individual characteristics and all time-varying common trends, reducing the possibility of omitted variable bias. In the DID model, policy implementation is usually considered exogenous, meaning that policy implementation is not directly affected by the explained variable, allowing DID to effectively avoid adverse causality problems. Therefore, the difference-in-differences model has become an important tool in the field of policy effectiveness evaluation and has been widely used in practice.

This study treats the promulgation of the Green Credit Guidelines as a quasi-natural experiment and constructs a difference-in-differences (DID) model to examine the impact of green credit policy on corporate green technological innovation. To test Hypothesis H1 proposed above, the DID model is specified as follows:

$$Patent\_total_{it}=\beta_0+\beta_1(Treat_i\times Post_t)+\beta_c Controls_{it}+\mu_i+\lambda_t+\varepsilon_{it} \quad (1)$$

$$Patent\_inv_{it}=\beta_0+\beta_1(Treat_i\times Post_t)+\beta_c Controls_{it}+\mu_i+\lambda_t+\varepsilon_{it} \quad (2)$$

$$Patent\_noninv_{it}=\beta_0+\beta_1(Treat_i\times Post_t)+\beta_c Controls_{it}+\mu_i+\lambda_t+\varepsilon_{it} \quad (3)$$

Here, the subscript i denotes firms and t denotes years. $Patent\_total_{it}$ represents the total number of green patent applications, $Patent\_inv_{it}$ denotes the number of green invention patent applications, and $Patent\_noninv_{it}$ represents the number of green utility model patent applications. The core explanatory variable is the interaction term (Treati×Postt), whose coefficient β1 is the parameter of focus in this study, capturing the average treatment effect of green credit policy implementation on green innovation of heavily polluting enterprises relative to non-heavily polluting enterprises. $Controls_{it}$ is a vector of time-varying control variables. In addition, the model controls for firm fixed effects μ_i , which are invariant over time, and year fixed effects λ_t, which are common across firms. ε_{it} denotes the idiosyncratic error term.

2.4.2.2 Parallel Trend Test Model

A key prerequisite for the validity of the difference-in-differences (DID) model is the parallel trends assumption, which requires that, prior to policy implementation, the treatment and control groups exhibit no systematic differences in their outcome trends. To test this assumption, this study constructs the following event-study model:

$$Patent\_total_{it}=\alpha_0+\sum_{k=-M}^{N}\beta_k(Treat_i\times Year_k)+\alpha_c Controls_{it}+\mu_i+\lambda_t+\varepsilon_{it} \quad (4)$$

$$Patent\_inv_{it}=\alpha_0+\sum_{k=-M}^{N}\beta_k(Treat_i\times Year_k)+\alpha_c Controls_{it}+\mu_i+\lambda_t+\varepsilon_{it} \quad (5)$$

$$Patent\_noninv_{it}=\alpha_0+\sum_{k=-M}^{N}\beta_k(Treat_i\times Year_k)+\alpha_c Controls_{it}+\mu_i+\lambda_t+\varepsilon_{it} \quad (6)$$

Here, $Year_k$ is a series of annual dummy variables based on the year of policy implementation (2012). This paper selects the year before policy implementation (2011) as the baseline group. The coefficient β_k reflects the differences between the treatment group and the control group in each year before and after policy implementation. If the coefficient β_k

(k<0) in each period before policy implementation is not significantly different from zero, it indicates that the parallel trend hypothesis is valid.

2.4.2.3 Mediation Effect Model

To further and more rigorously verify the validity of these transmission channels from a statistical perspective and to quantify their relative importance, this chapter adopts the causal steps approach proposed by Baron and Kenny (1986) to construct mediation effect models and test the previously stated hypotheses H2, H3, and H4. According to the logic of the causal steps approach, a complete mediation effect test consists of the following three models.

First, the total effect of the core explanatory variable on the dependent variable is examined, which corresponds to the baseline model in this study:

$$Patent\_total_{it}=\beta_0+c(Treat_i\times Post_t)+\beta_c Controls_{it}+\mu_i+\lambda_t+\varepsilon_{it} \quad (7)$$

Here, coefficient c represents the total effect of green credit policies on corporate green innovation.

Secondly, the impact of the core explanatory variables on the mediating variables is examined:

$$Mediator_{it}=\alpha_0+a(Treat_i\times Post_t)+\alpha_c Controls_{it}+\mu_i+\lambda_t+\varepsilon_{it} \quad (8)$$

Here, $Mediator_{it}$ represents the mediating variables, including the Financing Constraint , Environmental Information Disclosure level and R&D Intensity (Rd_rate). The coefficient 'a' measures the impact of policies on the mediating variables.

Finally, both the core explanatory variables and the mediating variables are included in the model to examine their joint impact on the explained variable:

$$Patent\_total_{it}=\gamma_0+c'(Treat_i\times Post_t)+b(Mediator_{it})+\gamma_c Controls_{it}+\mu_i+\lambda_t+\varepsilon_{it} \quad (9)$$

The criterion for determining the existence of a mediation effect is that both coefficient a and coefficient b are statistically significant. Under this condition, if coefficient c′ decreases relative to coefficient c but remains statistically significant, a partial mediation effect is indicated; if coefficient c′ is no longer statistically significant, this suggests a full mediation effect.

2.4.2.4 Moderating Effect Model

To examine the heterogeneous effects of policy outcomes under different contextual conditions, this study extends the baseline model by incorporating moderating variables and their triple interaction terms with the core explanatory variable, in order to test Hypotheses H5 and H6 proposed above. The specific regression model is specified as follows:

$$patent\_total_{it}=\gamma_0+\gamma_1(Treat_i\times Post_t\times Z_{it})+\gamma_2(Treat_i\times Post_t)+\gamma_3 Z_{it}+\gamma_c Controls_{it}+\mu_i+\lambda_t+\varepsilon_{it} \quad (10)$$

Here, Z_{it} represents the moderating variable. This paper focuses on the coefficient γ_1 of the triple interaction term, whose significance, sign, and magnitude reflect the direction and strength of the moderating variable Z_{it} influence on the policy effect. To address potential heteroscedasticity and serial correlation, all regressions in this paper employ robust standard errors clustered to the firm level.

2.4.2.5 Heterogeneity Analysis

To further uncover the heterogeneous effects of green credit policy on firms' green technological innovation, this study conducts heterogeneity analyses along five dimensions: ownership structure, regional distribution, firm size, pollution intensity, and patent type. This approach aims to examine how policy effects vary across different firm characteristics and environmental contexts, as well as to explore the underlying mechanisms.

(1) Heterogeneity of Ownership Structure

State-owned enterprises (SOEs) and non-state-owned enterprises (SOEs) play different roles in China's economic system, each with its unique function, but together they provide a solid material foundation for the country's economic development. SOEs are the core pillar of my country's economic system, especially dominating key industries such as energy, transportation, communications, and finance, as well as infrastructure construction. Non-state-owned enterprises (SOEs) are an important component of my country's socialist market economy. They aim to maximize profits and continuously optimize resource allocation and improve production efficiency through market competition. At the same time, non-state-owned enterprises also play a vital role in promoting economic growth, creating employment, and meeting diverse market demands. For both SOEs and non-state-owned enterprises, funding is a crucial factor constraining their development. Funding plays a vital role in enterprise operation, expansion, innovation, and technological transformation.

Compared to non-state-owned enterprises, SOEs typically have closer ties with the government and financial institutions, respond more directly to policy signals, and are more likely to obtain resource allocation and financial support in green credit. Furthermore, SOEs have a stronger willingness to assume responsibility for policy demonstration and green transformation. Under the guidance of the "dual-carbon" strategic goals and sustainable development policies, they are more likely to transform green credit funds into green innovation inputs, thereby promoting green technology innovation output.

(2) Heterogeneity of Firm Size

Differences in enterprise size may lead to significant heterogeneity in the impact of green credit on promoting green technology innovation. Large-scale enterprises typically possess more comprehensive financing channels, stronger risk resistance capabilities, and higher resource integration levels, enabling them to gain greater trust and support from financial institutions in green credit policies. Small-scale enterprises, due to their smaller asset size, insufficient information disclosure, and lower credit ratings, often face more severe financing constraints, making it difficult to fully utilize green credit funds to promote green technology innovation. Compared to small and medium-sized enterprises (SMEs), large enterprises have often undergone long-term accumulation and development, resulting in relatively stronger productivity, profitability, and debt repayment capabilities. Furthermore, their operating cash flow is more balanced, facilitating adjustments to their financing structure (Tong, 2011).

Theoretically, large-scale enterprises possess significant advantages in capital, technology, and management. On the one hand, their large fixed asset size and strong collateral capacity make it easier for them to meet banks' credit risk assessment requirements, thereby obtaining green credit support more quickly and fully. On the other hand, large enterprises possess economies of scale and learning effects in R&D investment, technology absorption, and transformation capabilities, enabling them to more effectively convert green credit funds into green innovation achievements, such as energy-saving and emission-reduction technologies, clean production processes, or green product designs. In contrast, small-scale enterprises have limited R&D capabilities, and the policy incentive effect of green credit may be offset by financing constraints and insufficient management capabilities.

（3）Industry heterogeneity

① Heterogeneity analysis between manufacturing and non-manufacturing industries

From an industry perspective, the impact of green credit policies on corporate green technology innovation may differ significantly between manufacturing and non-manufacturing sectors. Compared to non-manufacturing enterprises, manufacturing enterprises typically have higher resource consumption intensity, energy dependence, and pollution emission levels, facing stricter environmental regulations and a more urgent need for green transformation. Therefore, after the implementation of green credit policies, manufacturing enterprises are more susceptible to differentiated credit constraints and green financing incentives. To alleviate financing pressure, meet environmental requirements, and improve environmental performance, manufacturing enterprises are often more motivated to increase investment in green R&D, promote energy conservation and emission reduction, cleaner production, and green process transformation, thus exhibiting a more significant green technology innovation response.

At the same time, manufacturing enterprises have significant room for technological transformation in their production processes. Green technology innovation is often directly reflected in product upgrades, process optimization, equipment renewal, and pollution control. Therefore, the financial support and constraints provided by green credit policies are more easily translated into actual green innovation behavior. In contrast, non-manufacturing enterprises typically have relatively lower pollution emissions and weaker environmental regulatory pressure. Their green innovation activities are more reflected in management optimization, service model improvement, and low-carbon operations, with relatively lower quantifiability and patentability of technological innovation. Therefore, the role of green credit policies in promoting green technology innovation in non-manufacturing enterprises may be relatively limited.

② Analysis of Heterogeneity in Capital Intensity

From the perspective of factor input structure, enterprises with different capital intensities exhibit significant differences in financing needs, equipment upgrade pressures, and green transformation paths. This may lead to heterogeneous impacts of green credit policies on corporate green technology innovation. Enterprises with higher capital intensities typically rely more heavily on fixed assets and technological equipment. Green transformation often requires substantial capital investment for equipment upgrades, process modifications, and the application of environmental technologies. Therefore, their green innovation activities are more sensitive to external financing support. Green credit policies, by improving financing conditions, reducing financing costs, and guiding funds towards green projects, can more effectively alleviate the financial constraints of high-capital-intensive enterprises, thereby promoting their green technology innovation.

In contrast, enterprises with lower capital intensities are relatively less dependent on fixed assets and heavy equipment in their production and operations. Their innovation activities rely more on human capital, organizational management, and asset-light operations. Green innovation in these enterprises often manifests as management optimization, process improvement, or service model innovation, with relatively limited reliance on large-scale external credit funds. Therefore, while green credit policies may also incentivize them by improving the financing environment, their effect on promoting green technology innovation may not be as significant as that of high-capital-intensive enterprises.

Summary: Chapter 2

First, this chapter introduces the research methodology design. Centered on the scientific rigor, feasibility, and systematic nature of the study, this chapter constructs a comprehensive methodological framework. At the research paradigm level, the study is grounded in a positivist research philosophy and follows a logical pathway of “theoretical grounding → model construction → data testing → conclusion validation.” It adopts a complementary set of methods, including literature review, empirical analysis, statistical analysis, and comparative analysis. The study period is explicitly defined as the stages before and after the promulgation of China’s Green Credit Guidelines in 2012, ensuring the practical relevance and policy orientation of the research findings.

Second, the chapter provides a detailed description of the research design. Through an extensive review of the literature and the construction of a theoretical framework, the study formulates theoretical hypotheses on how green credit policy promotes corporate green technological innovation and conducts empirical analysis accordingly. The research methods include baseline regression analysis, robustness checks, mediation analysis, and moderation analysis, aiming to verify the mechanisms through which green credit policy operates and the conditions under which its effects are strengthened or weakened. By analyzing large-scale panel data, the study reveals both the magnitude of the impact of green credit policy on corporate green technological innovation and the specific pathways through which this impact is realized.

Third, the data collection and sample selection are described in detail. This study constructs a multi-dimensional fusion sample system of enterprises, industries, and regions based on multi-source data such as CSMAR, WIND, CNRDS, ESG databases, patent databases, and statistical yearbooks, providing a reliable data foundation for empirical research. The study covers 5,332 listed companies, with a total of 53,536 observation data. Data analysis was conducted using software such as Excel and Stata 17.0.

Finally, the chapter elaborates on variable selection and model construction. Focusing on corporate green technological innovation as the dependent variable and green credit policy as the key explanatory variable, the study incorporates mediating variables (financing constraints, R&D investment, and environmental information disclosure), moderating variables (institutional investor ownership and executives' financial background, among others), as well as a set of control variables, thereby forming a logically coherent indicator system. Based on this framework, the chapter constructs a difference-in-differences (DID) model, a parallel trends test model, mediation effect models, and moderation effect models. In addition, a heterogeneity analysis framework was constructed based on the nature of corporate ownership, corporate size, and industry heterogeneity to reveal the multi-level differences in the effects of green credit policies and their boundaries.

Overall, by systematically addressing research methodology design, research design, data collection, variable selection, and model construction, this chapter establishes a rigorous, internally consistent, and highly operational methodological system, providing a solid methodological foundation and technical support for subsequent empirical testing and theoretical extension.

CHAPTER 3. EMPIRICAL ANALYSIS

3.1Current Status of Green Credit Policy and Green Technological Innovation

3.1.1 Development Status of China's Green Credit Policy

3.1.1.1 Evolution of China's Green Credit Policy

The development of China's green credit policy can be traced back to the early 1990s. After progressing through multiple stages of development, it has gradually evolved into the current institutional system and practical framework.

(1) The Emergence Stage of China's Green Credit Policy (1995–2006)

From the founding of the People's Republic of China until 1971, China had not yet established a specialized environmental management authority, and the development of environmental economic policies and institutional frameworks was largely absent. Policy formulation during this period remained mainly at the macro level, providing general directional guidance, while implementation and enforcement at the operational level were relatively limited.

In 1995, the People's Bank of China issued the Notice on the Guiding Principles and Implementation Measures for Integrating Credit Policy with Environmental Protection, which explicitly required financial institutions to incorporate national environmental protection policies into credit decision-making. This document is widely regarded as the starting point and a major milestone in the practice of China's green credit policy. Subsequently, government agencies and regulatory authorities required the financial sector to systematically embed environmental considerations into lending activities, actively support the development of environmental protection industries, optimize the allocation of credit resources, and reduce financial support for overcapacity industries. At the same time, the State Environmental Protection Administration and the China Securities Regulatory Commission successively issued guidelines on environmental audits and information disclosure, leading capital markets to gradually pay greater attention to corporate environmental behavior.

(2) The Exploratory Stage of China's Green Credit Policy (2007–2011)

In 2007, environmental enforcement information was incorporated into the credit reporting system of the People's Bank of China, and a preliminary information-sharing and coordination mechanism was established between environmental regulatory authorities and financial regulators. This integration strengthened environmental regulation through financial instruments. Subsequently, the People's Bank of China, the former Ministry of Environmental Protection, and the former China Banking Regulatory Commission jointly issued a series of policies. On the one hand, these policies strictly restricted credit to high energy-consuming and highly polluting ("two-high") enterprises; on the other hand, they increased financial support for energy-saving and environmental protection industries, thereby promoting green economic transformation and sustainable development.

In February 2007, the People's Bank of China, the former China Banking Regulatory Commission, the Ministry of Environmental Protection, and the National Development and Reform Commission jointly issued documents such as Opinions on Implementing Environmental Protection Laws and Regulations and Preventing Credit Risks, marking the entry of China's green credit policy into a stage of systematic exploration and gradual implementation.

(3) The Growth Stage of China's Green Credit Policy (2012–Present)

On January 29, 2012, the former China Banking Regulatory Commission (CBRC) issued the Green Credit Guidelines. As the first official document to systematically regulate green credit activities of banking financial institutions, the Guidelines clarified the development principles and operational requirements of green credit. Subsequently, in 2013 and 2014, the CBRC introduced green credit statistical systems and key performance evaluation indicators, thereby establishing a relatively comprehensive framework for green credit statistics and supervision. At the same time, national industrial policies continued to emphasize support for energy-saving and environmental protection industries, while prioritizing industrial restructuring and the reduction of excess capacity.

Since 2016, the People's Bank of China, together with seven other ministries and commissions, has issued the Guiding Opinions on Building a Green Financial System, providing top-level design for the development of China's green financial system and marking a new stage in the advancement of green finance. In March 2024, the People's Bank of China, jointly with six other departments, released the Guiding Opinions on Further Strengthening Financial Support for Green and Low-Carbon Development, which further emphasized enhancing green credit support and proposed measures such as optimizing green credit operational processes and innovating financial products and service models.

Overall, with the continuous improvement of the policy framework and the steady expansion of market scale, green credit in China has played an increasingly important supporting role in promoting green economic development and achieving the goals of carbon peaking and carbon neutrality.

Table 8. *Relevant policy documents on green credit issued by China (partial list)*

years	Issuing authority	Policy documents
2007	Former China Banking and Insurance Regulatory Commission, State Environmental Protection Administration, and People's Bank of China	《Opinions on Implementing Environmental Protection Policies and Regulations and Preventing Credit Risks》
2012	Former China Banking Regulatory Commission	《Green Credit Guidelines》
2013	Former China Banking Regulatory Commission	《Green Credit Statistics System》
2014	Former China Banking Regulatory Commission	《Key evaluation indicators for the implementation of green credit》
2016	Seven ministries including the Ministry of Finance and the People's Bank of China	《Guiding Opinions on Building a Green Finance System》
2018	People's Bank of China	《Notice on Conducting Performance Evaluation of Green Credit by Banking Deposit-Taking Financial Institutions》
2020	Ministry of Finance	《Commercial Bank Performance Evaluation Method》
2021	People's Bank of China	《Green Finance Evaluation Scheme for Banking Financial Institutions》
2022	China Banking and Insurance Regulatory Commission	《Green Finance Guidelines for the Banking and Insurance Industries》
2024	People's Bank of China, Ministry of Ecology and Environment, State Financial Regulatory Commission, China Securities Regulatory Commission	《Opinions on Leveraging the Role of Green Finance in Serving the Construction of a Beautiful China》

3.1.1.2 Rapid Growth of China's Green Credit

In recent years, driven by strong national policy support, China’s green finance sector has experienced rapid growth. This expansion has been reflected not only in a substantial increase in scale, but also in notable improvements in service quality and business sophistication. As shown in Figure 5, the outstanding balance of green credit issued by Chinese commercial banks amounted to RMB 8.23 trillion in 2018. It rose to RMB 10.22 trillion in 2019, representing a year-on-year increase of approximately 24%, and further increased to RMB 11.95 trillion in 2020, with a growth rate of about 17%. In 2021, the balance surged to RMB 15.90 trillion, marking a clear acceleration in growth. In 2022, green credit outstanding exceeded RMB 20 trillion for the first time, reaching RMB 22.03 trillion. This upward trajectory continued in 2023, when the balance climbed to RMB 30.08 trillion, and further reached a new high of RMB 36.60 trillion in 2024. Overall, over a six-year period, the outstanding balance of green credit increased by more than 340%, exhibiting a pronounced leapfrog expansion.

This rapid growth has been driven primarily by the top-level guidance of China's "dual carbon" goals, the strengthening of regulatory assessment and incentive mechanisms, and continuous improvements in banks' internal green finance governance structures and product systems. Green credit has thus become a core financial instrument within China's banking system for supporting the low-carbon transition and promoting sustainable development.

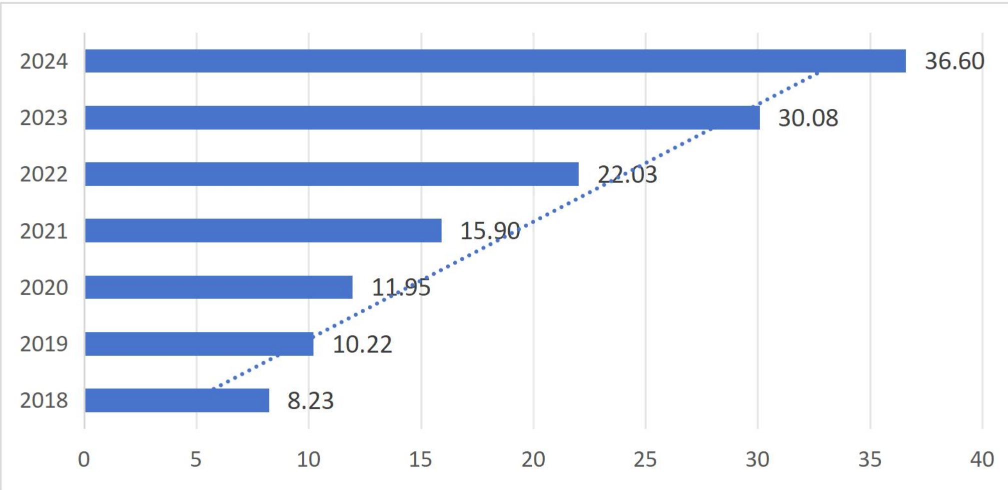


Figure 5. *Development of Green Credit in China, 2018-2024 (Unit: Trillion Yuan)*

Data Source: Official Website of the People's Bank of China

As shown in Figure 6, from 2018 to 2024, the proportion of green credit in the total credit balance of financial institutions in China showed a clear and accelerating upward trend, increasing from 6.04% in 2018 to 14.31% in 2024, a growth of approximately 2.37 times in six years. From 2018 to 2020, the proportion rose slightly from 6.04% to 6.92%, an increase of only 0.88 percentage points, indicating a slow accumulation period in the construction of the green credit system and the improvement of risk identification capabilities. Since 2021, the proportion has rapidly increased from 8.25% to 14.31%, a 6.06 percentage point increase between 2021 and 2024, entering a period of rapid development driven by the intensive introduction of policies such as the Carbon Peak Action Plan and the Green Finance Standards System. Various financial institutions have increased their lending to green projects, leading to a significant increase in demand for green financing. Overall, the proportion of green credit continues to rise and the growth rate is accelerating, which reflects that the green and low-carbon transformation has entered a critical stage, and also indicates that green credit has gradually evolved from a policy support tool into a mainstream credit product in the financial system, playing an important role in optimizing the credit structure.

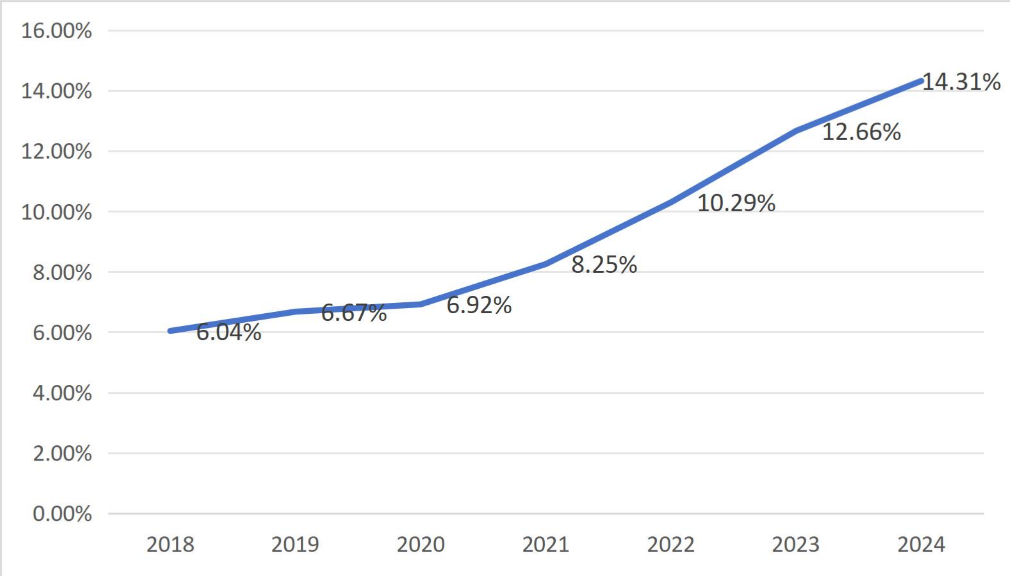


Figure 6. *Proportion of Green Credit in Financial Institutions' Outstanding Loans in China, 2018-2024*

Data Source: Official Website of the People's Bank of China

As shown in Figure 7, from 2018 to 2024, the outstanding balance of green loans in the electricity, heat, gas and water production and supply industry increased from approximately RMB 2.6 trillion to approximately RMB 8.85 trillion. Although the proportion decreased slightly, it remains a fundamental pillar of green credit. The growth was mainly driven by projects such as new energy power generation, clean energy supply and energy-saving renovation. The transportation, warehousing and postal industry increased from approximately RMB 3.66 trillion to approximately RMB 5.95 trillion, with a relatively stable growth rate, reflecting the continuous investment in new energy vehicles, rail transit and green logistics, indicating that the construction of the green transportation system is in a steady progress stage. The "other industries" saw the most significant increase, jumping from approximately RMB 1.96 trillion to approximately RMB 21.8 trillion, a more than tenfold increase in six years. It covers emerging fields such as clean manufacturing, energy-saving buildings, environmental protection services and circular economy, indicating that green credit is rapidly expanding from the traditional energy and transportation sectors to a more diversified green industrial system.

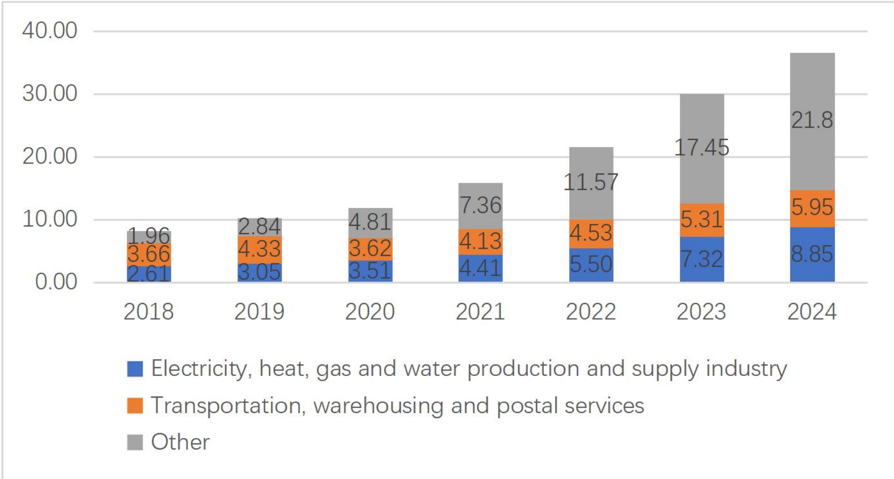


Figure 7. Statistics on the allocation of green loans in China's industry, 2018-2024.

Data source: Official website of the People's Bank of China.

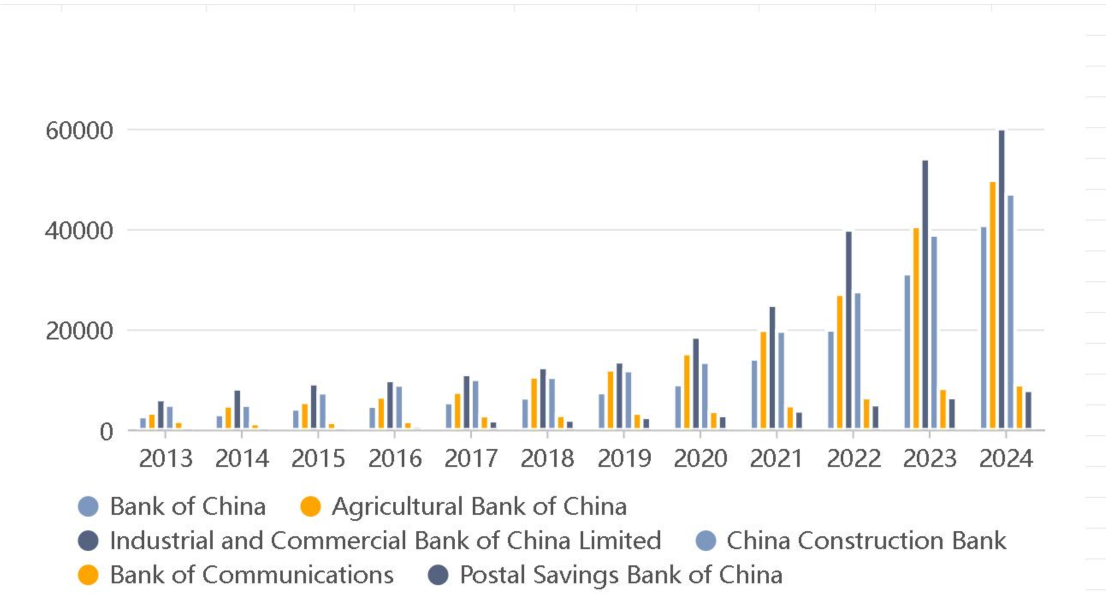


Figure 8. *Green Loan Balance of China's Six Major State-Owned Banks, 2013-2024*

Data Source: Wind Database

As shown in Figure 8, since 2013, the outstanding balance of green loans from China's six major state-owned banks has continued to grow rapidly. Following the national "dual-carbon target" proposed in 2020, the demand for green financing accelerated, driving a significant expansion in the scale of green loans. Looking at the different phases, 2013-2017 was a period of stable growth, with relatively balanced increases across banks, and green loans gradually extended from traditional environmental governance to areas such as new energy and energy-saving renovations. Between 2018 and 2020, with the gradual improvement of systems such as green bonds, green ratings, and green loan assessments, and the continuous improvement of the green finance policy system, the scale of green loans increased significantly. From 2020 to 2024, driven by the "carbon peaking and carbon neutrality" strategy, green loans entered a period of rapid expansion, reaching trillions of yuan, with many banks achieving double-digit annual growth rates, and some years seeing growth rates approaching double digits. By the end of 2024, the total outstanding balance of green loans from the six major banks approached 20 trillion yuan, becoming an important financial support force for promoting the green and low-carbon transformation of my country's real economy.

3.1.1.3 The Increasing Diversification of Green Credit Products in China

Leveraging their diversified financial product systems, financial institutions are able to provide comprehensive product packages and integrated services for green projects, among which green credit accounts for the largest share. In terms of product classification, financial products can be divided into two broad categories based on the type of borrower: corporate financial products for enterprises and retail financial products for individuals. From the perspective of fund usage, they can be classified into project loans, fixed-asset loans, and working capital loans.

Table 9. *Classification of China's Green Credit Products*

Classification Dimensions		**category**	**Description/Example**
Borrowing entity	Corporate financial products	Green project loans	Loans specifically designed to support green projects, such as clean energy and environmental protection facilities.
		Energy conservation and emission reduction loans	Loans for energy-saving and emission-reduction technologies or projects.
		Carbon finance products	Financial products related to carbon emission trading, such as carbon trading financial advisors and carbon-backed loans.
		Green supply chain finance	Support the financing needs of upstream and downstream enterprises in the green supply chain.
		Other	Such as green bonds, green notes, and green trusts.
	Retail financial products	New energy vehicle loans	Loans are available to support individuals purchasing new energy vehicles.。
		Green consumer loans	Loans that support individuals in green consumption, such as purchasing environmentally friendly home appliances and green building materials.
		Green Credit Card	Credit card products that encourage green consumption offer green spending points and discounts.
Use of funds	Project	Wind power project loans	Loans specifically for wind power projects.

Classification Dimensions		category	Description/Example
	Loans	Photovoltaic project loans	Loans specifically for photovoltaic projects.
		Other green project loans	Loans for projects such as green building, green agriculture, and green forestry.
	Fixed asset loans	Environmental equipment loan	Loans used to purchase environmental protection equipment.
		Clean energy facility loans	Loans for the construction or renovation of clean energy facilities.
		Other fixed asset loans	Loans for projects such as green industrial park construction and green data centers.
	Working capital loans	Green Enterprise Working Capital Loans	Loans to support the daily operations of green enterprises.
		Loans to upstream and downstream enterprises in the green supply chain	Loans to support the daily operations of upstream and downstream enterprises in the green supply chain.

Prior to the official launch of the national unified carbon trading market in July 2021, seven pilot carbon trading regions—Beijing, Tianjin, Shanghai, Chongqing, Guangdong, Hubei, and Shenzhen—had already conducted extensive and forward-looking explorations in the areas of carbon emission trading and related financial product innovation. These regions not only successfully launched the basic mechanism of carbon emission trading but also extended it to carbon emission derivatives and carbon market investment and financing activities, successively achieving several market-first transactions.

After the launch of the national carbon market, the enthusiasm of various regions to participate in carbon finance has significantly increased. Among them, carbon emission rights pledge financing, as an important financial innovation, allows enterprises to use their carbon assets (including carbon emission allowances and Certified Emission Reductions, CCERs) as collateral to apply for loans from commercial banks and other financial institutions. Carbon emission rights, as environmental rights, can be traded in the secondary market and bought and sold on exchanges, realizing value realization.

Through carbon emission rights pledge financing, enterprises can manage and revitalize carbon assets more efficiently, promoting resource allocation and value enhancement. Since the launch of the national carbon market, major energy-consuming provinces such as Shandong and Hebei, as well as Zhejiang Province, the birthplace of the "Two Mountains Theory," have successively launched carbon emission rights pledge loan businesses, further promoting the in-depth development of carbon finance.

3.1.2 The Current State of Green Technological Innovation among Chinese Enterprises

3.1.3.1 Overall Situation of Green Technological Innovation in Chinese Enterprises

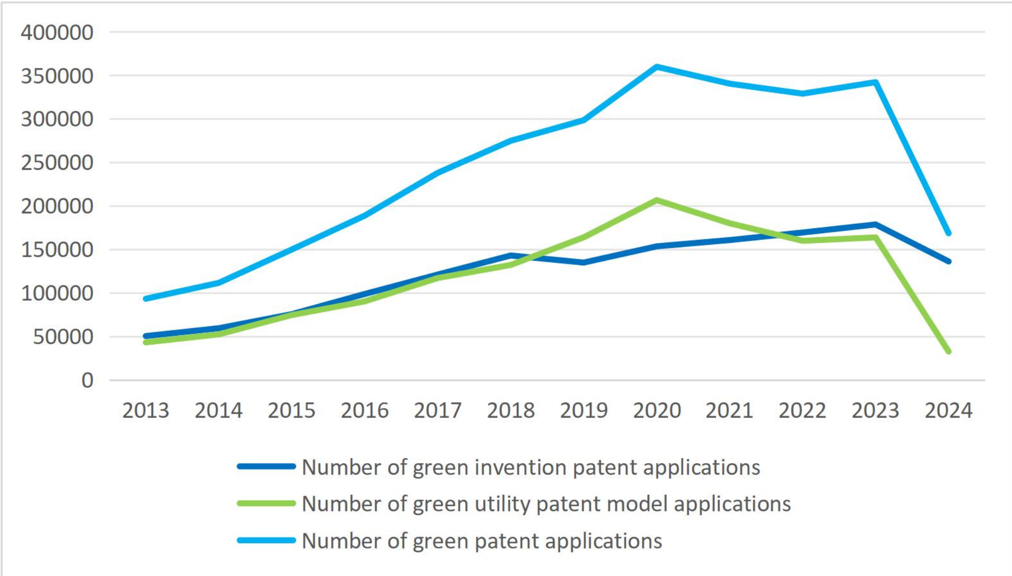


Figure 9. *China's Green Patent Applications, 2013-2024.*
Data Source: China National Research Data Service Platform (CNRDS)

Figure 9 illustrates the development trend of green technological innovation among Chinese enterprises. Between 2013 and 2024, green patent applications in China exhibited a clear stage-based pattern characterized by "rapid growth–accelerated expansion–high-level decline." From 2013 to 2017, the total number of green patent applications increased from 93,078 to 237,824, representing a growth of approximately 155%, driven primarily by the promotion of green manufacturing, the diffusion of energy-saving and environmental protection technologies, and the initiation of new energy policies. During 2018–2020, green patent applications entered a phase of accelerated expansion, rising from 274,713 to a peak of 359,778, fueled by the strengthening of the "green development" strategy and technological breakthroughs in new energy vehicles, photovoltaic power, and wind energy. From 2021 to 2023, application volumes remained at a high plateau of around 330,000–340,000. However, in 2024, the number of applications dropped sharply to 168,334, indicating that after years of rapid growth, green innovation has entered a phase of structural contraction under the combined effects of tighter patent examination policies and industrial cycle adjustments.

From the perspective of patent structure, applications for green invention patents increased from 50,168 in 2013 to 178,473 in 2023, and although they declined to 135,948 in 2024, the overall trend remains relatively stable, indicating the sustained accumulation of high-quality green innovation. In contrast, green utility model patents exhibit substantial volatility: applications rose from 42,910 in 2013 to a peak of 206,447 in 2020, but then dropped sharply to 32,386 in 2024, representing a decline of 84%, which suggests a high sensitivity to policy changes and the patent examination environment. Overall, China's green patent applications reached their peak in 2020, while the pronounced decline in 2024 is mainly attributable to the sharp reduction in utility model patents. This pattern indicates a transition of green innovation from quantitative expansion toward qualitative improvement, with the relatively steady growth of green invention patents and the contraction of utility model patents jointly reflecting a structural optimization of the green technological innovation system.

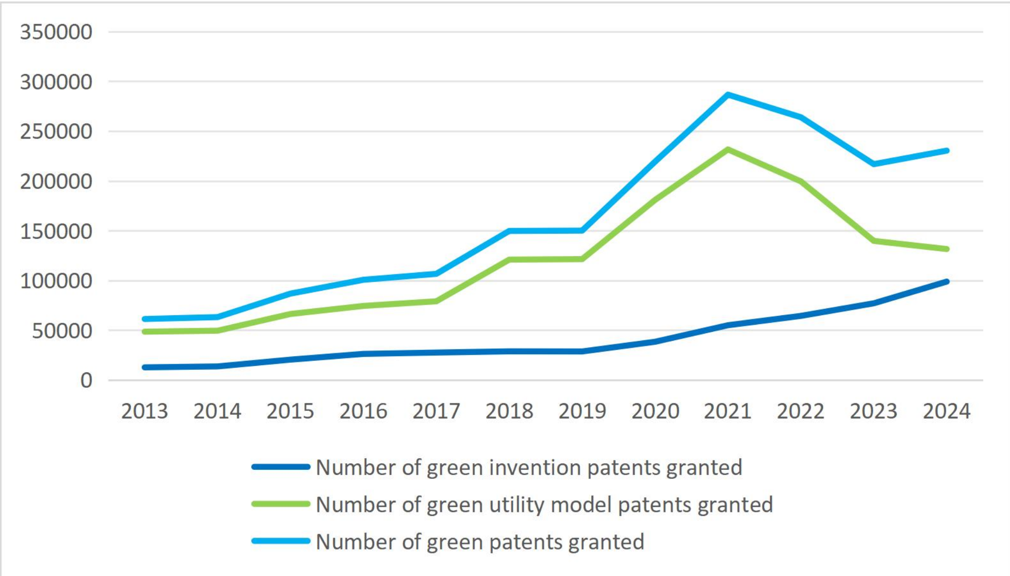


Figure 10. *Number of Green Patents Granted in China, 2013-2024.*
Data Source: China National Research Data Service Platform (CNRDS)

As shown in Figure 10, from 2013 to 2024, the number of green patents granted in my country showed a continuous growth trend, reaching a peak in 2021, and then entering a high-level adjustment phase. The total number of grants increased from 61,283 in 2013 to 286,609 in 2021, approximately 4.7 times the starting point, before falling back to 230,379 in 2024. Looking at the different phases, the period from 2013 to 2017 was a period of steady growth, with the number of authorized patents increasing from 61,283 to 106,640, benefiting from the expansion of green industries such as new energy and energy conservation and environmental protection. The period from 2018 to 2021 saw a period of rapid expansion, with the number of authorized patents rising from 149,734 to 286,609, with a particularly significant increase in 2020 and 2021, which was closely related to the proposal of the "carbon neutrality" goal and the concentrated outbreak of green industries. The period from 2022 to 2024 is a period of high-level adjustment, with the number of authorized patents fluctuating but remaining in the range of 210,000 to 260,000, reflecting that my country's green technology innovation activities are trending towards a stable development stage.

From the perspective of patent type, green invention patents and green utility model patents exhibit a significant structural differentiation. The number of green invention patents granted increased from 12,739 in 2013 to 98,835 in 2024, an increase of over 6.7 times, and has maintained a steady upward trend, indicating higher technological content and stricter examination standards, better reflecting the enhancement of my country's high-quality green innovation capabilities. In contrast, the number of green utility model patents granted is more sensitive to policy and the examination environment. It rapidly increased from 48,544 in 2013 to a peak of 231,590 in 2021, but then declined to 131,544 in 2024, a 43% decrease from its peak. This "rise then fall" fluctuation mainly stems from early concentrated innovation in fields such as new energy equipment and energy-saving technologies, as well as the contraction in grants resulting from the country's strengthened governance of intellectual property quality and the reduction of low quality patents after 2022. Overall, the steady growth of green invention patents and the significant fluctuations in green utility model patents together determine the changes in the total number of green patents granted, reflecting that my country's green innovation system is accelerating its transformation from quantitative expansion to quality improvement.

3.1.3.2 Regional Distribution of Green Technological Innovation among Chinese Enterprises

There are significant regional disparities in the number of green patent applications across eastern, central, and western China. The eastern region consistently records far higher application volumes than the central and western regions. Although the latter two regions start from a lower base, they exhibit a general upward trend over time. Figure 11 illustrates the trends in green patent applications in eastern, central, and western China from 2013 to 2024. Green patent applications in the eastern region increased continuously and reached a peak during 2019–2020. Although they declined slightly thereafter, they remained at a relatively high level overall, underscoring the region’s pronounced advantages in green innovation. In the central and western regions, application volumes rose steadily during 2013–2018 and, despite some fluctuations thereafter, maintained relatively stable trajectories, indicating both growth potential and resilience in green innovation. Overall, the eastern region functions as the core engine of China's green innovation, the central region is in a phase of steady improvement, and the western region shows catch-up potential but still lags significantly behind the eastern region.

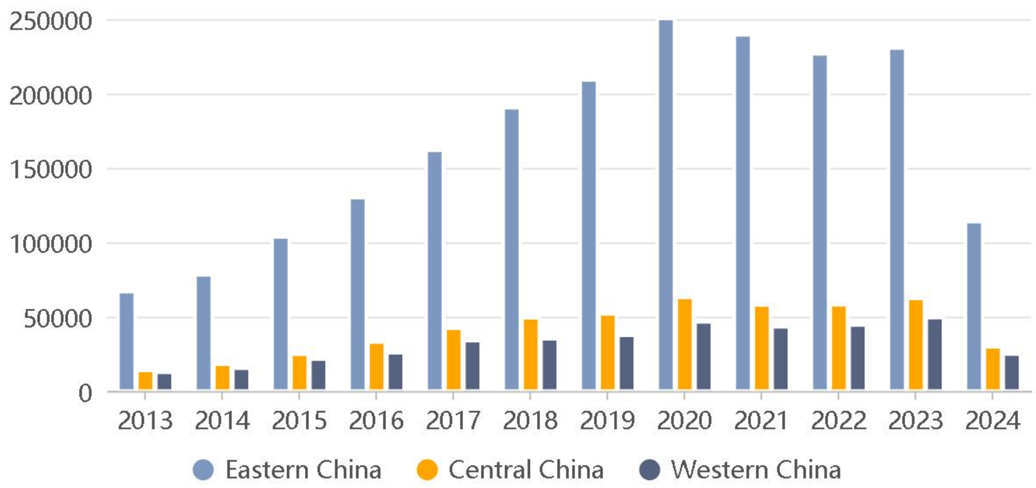


Figure 11. *Green Patent Applications in China's Eastern, Central, and Western Regions, 2013-2024.*
Data Source: China National Research Data Service Platform (CNRDS)

As shown in Figure 12, the number of green patent grants in China's eastern, central, and western regions exhibits pronounced regional disparities over the period 2013–2024. The eastern region has consistently maintained an absolute lead, with the number of granted patents rising steadily and reaching a peak during 2019–2021, surpassing 190,000 in 2021. Although the total declined somewhat thereafter, it has remained the highest nationwide, reflecting the region's strong advantages in innovation resources, technological foundations, and the agglomeration of green industries. In the central region, the number of green patent grants increased steadily between 2013 and 2018 and, despite subsequent fluctuations, generally remained in the range of 30,000–50,000, indicating a certain level of innovation potential in manufacturing upgrading and energy-saving and environmental protection sectors. The western region, while smaller in scale, experienced notable growth from 2013 to 2020 and achieved a phase of accelerated expansion in 2020–2021, reflecting growth momentum driven by clean energy development and ecological governance. Overall, the spatial pattern of green patent grants in China can be characterized as “strong in the east, stable in the center, and weaker but with potential in the west.” The eastern region serves as the core engine of green innovation, the central region maintains steady progress, and the western region, although still lagging behind, retains considerable catch-up potential.

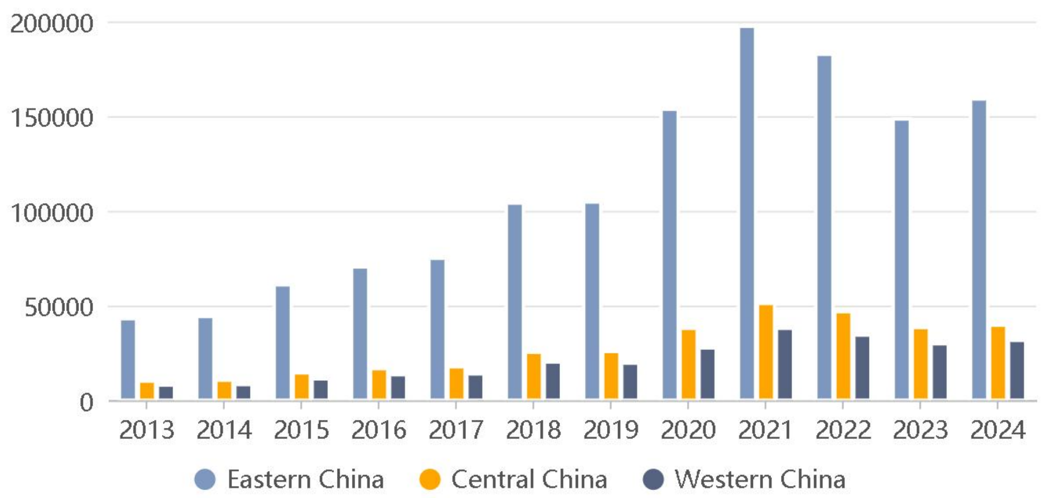


Figure 12. *Number of Green Patents Granted in China's Eastern, Central, and Western Regions, 2013-2024.*
Data Source: China National Research Data Service Platform (CNRDS)

The advantages of the eastern region are mainly attributable to its more developed economic base, higher technological capacity, and stronger educational resources, which together have driven the sustained growth in green patent applications. Although the central region started from a relatively lower base, it has experienced rapid economic development in recent years with strong support from national and local policies, alongside continuous improvements in science, technology, and education, thereby exhibiting a clear upward trend. The western region, constrained by geographic location and resource endowments, remains relatively lagging in economic development; however, under the impetus of national strategies and regional policies, it is gradually accelerating its development pace and striving to narrow the gap with the eastern and central regions.

Overall, the regional pattern of green patent applications in China can be characterized as “the east leading, with the central and western regions catching up.” Looking ahead, with the country’s sustained emphasis on green development and the continuous enhancement of technological innovation capacity, the number of green patent applications is expected to keep rising, further promoting the diffusion of green technologies and the achievement of sustainable development goals.

3.2 Analysis of the Impact of Green Credit Policies on Enterprise Green Technology Innovation

3.2.1 Descriptive Statistics

Before conducting the econometric regression analysis, this section first reports descriptive statistics for all variables included in the study, with the results presented in Table 10. Regarding the dependent variables, the mean values of corporate green innovation output (Patent_total), green invention patents (Patent_inv), and green utility model patents (Patent_noninv) are 0.679, 0.445, and 0.424, respectively, with relatively large standard deviations. This indicates that the overall level of green innovation among Chinese listed companies is relatively low, while substantial heterogeneity exists across firms.

The descriptive statistics for the moderating variables are as follows. The mean value of executives' financial background is 0.625, with a standard deviation of 0.484, suggesting that a majority of firms have executives with financial backgrounds and that firms with and without such backgrounds are relatively balanced in number. The mean shareholding ratio of institutional investors is 0.440, with a standard deviation of 0.248, indicating that institutional investors hold, on average, about 44% of equity in the sample firms, with considerable variation in ownership stakes across firms.

The descriptive statistics for the mediating variables are as follows. The mean value of financing constraints is 0.495, with a standard deviation of 0.282, indicating that firms in the sample face a moderate level of financing constraints, with some variation across companies. The mean level of environmental information disclosure is 7.173, with a standard deviation of 8.726, suggesting that the overall quality of environmental information disclosure is relatively low and varies substantially among firms. The mean value of R&D investment intensity is 3.483, with a standard deviation of 4.944, indicating that most firms invest relatively little in R&D, while the level of investment differs markedly across firms.

The mean value of the Post*Treat variable is 0.213, implying that observations belonging to the treatment group (heavily polluting firms) in the post-policy period account for approximately 21.3% of the total sample. This relatively balanced sample distribution provides a solid basis for the effective identification of the difference-in-differences model.

The control variables are described as follows: Company size has a mean of 22.13 and a standard deviation of 1.425, indicating that companies are relatively large and their differences are small. Return on total assets has a mean of 0.0370 and a standard deviation of 0.0690, indicating that the overall return on assets is low, and there are significant differences in returns among companies, with some companies potentially showing higher or lower returns. Years on the market has a mean of 2.034 and a standard deviation of 0.935, indicating that most companies have been listed for a relatively short period, and the duration of listing fluctuates significantly. The debt-to-equity ratio has a mean of 0.433 and a standard deviation of 0.221, indicating that the average leverage ratio of companies is approximately 43%, and there are significant differences in debt-to-equity ratios among companies. Growth rate has a mean of 0.154 and a standard deviation of 0.414, indicating that most companies have low growth rates, and there are significant differences in growth rates. The shareholding ratio of the largest shareholder has a mean of 0.338 and a standard deviation of 0.149, indicating that the largest shareholder holds approximately 33.8% of the shares, and there are significant differences in shareholding ratios among shareholders.

Overall, the means and standard deviations of the mediating, moderating, and control variables fall within reasonable ranges, and no obvious extreme outliers are observed.

Table 10. *Descriptive statistics*

Variable	N	Mean	SD
Patent_total	53536	0.679	0.999
Patent_inv	53536	0.445	0.804
Patent_noninv	53536	0.424	0.764
FinBack	53536	0.625	0.484
Lis	53536	0.440	0.248
FC	53536	0.495	0.282
CEID	53536	7.173	8.726
RD rate	53536	3.483	4.944
Post*Treat	53536	0.213	0.409
Size	53536	22.130	1.425
ROA	53536	0.037	0.069
ListAge	53536	2.034	0.935
Lev	53536	0.433	0.221
Growth	53536	0.154	0.414
Top1_Share	53536	0.338	0.149

3.2.2 Correlation analysis

Table 11 presents the Pearson correlation coefficient matrix of the main variables, aiming to preliminarily examine the relationships among the variables and test for the existence of serious multicollinearity.

First, regarding the correlation between the core explanatory variables and the explained variable, the green credit policy variable (Post×Treat) shows a significant positive correlation with the enterprise green technology innovation index. Specifically, the correlation coefficient between Post×Treat and the total number of green patents (Patent_total) is 0.1562, with green invention patents (Patent_inv) it is 0.1471, and with green non-invention patents (Patent_noninv) it is 0.1589, all significant at the 1% level. This indicates that after the implementation of the green credit policy, the overall level of enterprise green technology innovation shows an upward trend, preliminarily suggesting that the green credit policy may have a promoting effect on enterprise green technology innovation; however, its specific impact still needs further verification through subsequent regression analysis.

Secondly, regarding the correlation between different types of green patents, a strong positive correlation is observed between the total number of green patents and both green invention patents and green non-invention patents. Specifically, the correlation coefficient between Patent_total and Patent_inv is 0.8932, the correlation coefficient between Patent_inv and Patent_noninv is 0.8264, and the correlation coefficient between Patent_inv and Patent_noninv is 0.7116, all significant at the 1% level. This indicates a strong consistency between the total number of green patents held by enterprises and the two sub-categories of patents, indirectly validating the rationality of the selected green technology innovation indicators.

Thirdly, regarding the correlation between control variables and enterprise green innovation, enterprise size (Size) shows a significant positive correlation with both the total number of green patents and its sub-indicators. The correlation coefficient between Size and Patent_total is 0.3864, indicating that larger enterprises typically possess more abundant funding and R&D resources, making them more capable of carrying out green technology innovation. A significant positive correlation was also found between return on assets (ROA) and green patent variables, indicating that companies with stronger profitability are better able to invest in innovation. A significant positive correlation was also found between the debt-to-equity ratio (Lev) and green innovation indicators, possibly suggesting that adequate financing can provide financial support for corporate technology research and development.

Furthermore, corporate growth showed a weak negative correlation with green patent indicators, while the shareholding ratio of the largest shareholder (Top1) showed a significant negative correlation with green innovation variables. This may indicate that excessive concentration of equity may, to some extent, inhibit corporate innovation activities. Meanwhile, the correlation between the company's listing age and green innovation indicators was relatively weak.

Finally, from the perspective of multicollinearity, except for the high correlation among green patent-related indicators, the correlation coefficients among the other explanatory variables are generally below 0.5, indicating a low overall level. This suggests that there is no serious multicollinearity problem among the model variables, allowing for subsequent regression analysis.

Table 11. *Correlation analysis*

Variables	**Patent_total**	**Patent_inv**	**Patent_noninv**	**Post*Treat**	**Size**	**ROA**	**ListAge**	**Lev**	**Growth**	**Top1_Share**
Patent_ total	1.000									
Patent_ inv	0.8932**	1.000								
Patent_ noninv	0.8264**	0.7116**	1.000							
Post*Treat	0.1562***	0.1471***	0.1589***	1.000						
Size	0.3864***	0.2914***	0.3892***	0.1271***	1.000					
ROA	0.0171***	0.0152***	0.0168***	0.1098***	0.0372***	1.000				
ListAge	-0.0163***	-0.0112***	-0.0170***	-0.0049***	0.0763***	0.3605***	1.000			
Lev	0.1156***	0.1085***	0.1207***	0.0052***	0.0048***	-0.1386***	0.2178***	1.000		
Growth	-0.0284***	-0.0198***	-0.0296***	0.0065***	-0.0281***	0.0362***	0.0049***	0.0585***	1.000	
Top1_Share	-0.0193***	-0.0145***	-0.0202***	0.0143***	0.0895***	0.1215***	-0.1186***	0.0935***	0.0925***	1.000

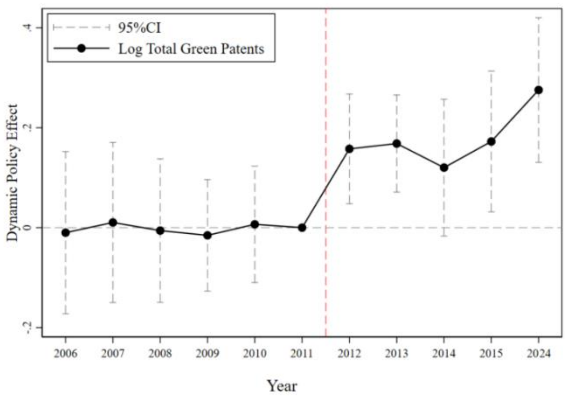
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

3.2.3 Parallel Trend Test

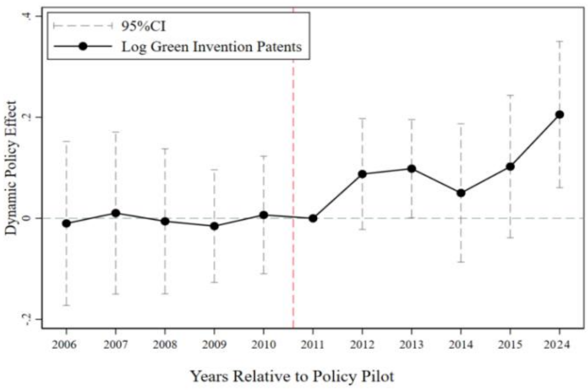
A key prerequisite for the validity of the difference-in-differences (DID) model is that, prior to policy implementation, the treatment group (heavily polluting firms) and the control group (non－heavily polluting firms) follow parallel trends in green innovation activities. To examine whether this assumption holds, this study employs an event-study approach to conduct a parallel trends test.

As shown in Figures 13, the horizontal axis represents the relative time to policy implementation (with 0 indicating the year of policy enactment), while the vertical axis reports the estimated policy effect coefficients for each year. The results indicate that in all pre-policy periods (t < 0), the estimated coefficients fluctuate around zero, and their 95% confidence intervals generally include zero. This suggests that there is no statistically significant difference in green innovation levels between the treatment and control groups prior to the policy, thereby supporting the parallel trends assumption.

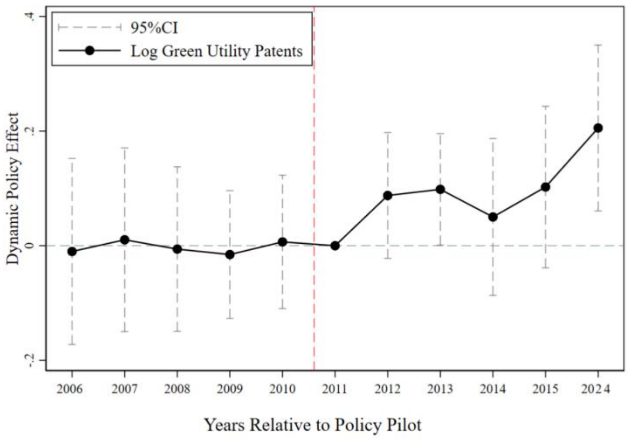
In contrast, starting from the year of policy implementation (t = 0) and thereafter, the estimated policy effects become significantly positive and exhibit an overall upward and fluctuating trend. This pattern indicates that the positive impact of the green credit policy is not only immediate but also persistent over time, reflecting a dynamic and cumulative effect on firms' green innovation.



(a) Total Green Patents



(b) Green Invention Patent



(C) Green Utility Patent

Figure 13. *Parallel trend test - event study method*

Note: The first period is used as the baseline period, and a 95% confidence interval is used.

3.2.4 Baseline Regression Analysis

To ensure the scientific rigor and accuracy of the empirical results and to identify the most appropriate estimation method for the panel data used in this study, a series of standard statistical tests were conducted prior to the baseline regression analysis. As reported in Table 12, an F-test was first performed to examine the presence of individual effects. The results show that the F-statistic is 12.78 with a corresponding p-value of 0.000, which is far below the 1% significance level. This strongly rejects the null hypothesis of no individual effects, indicating that the fixed effects model is preferable to the pooled OLS model.

Subsequently, to further choose between the fixed effects and random effects models, a Hausman test was conducted. The results yield a chi-square statistic of 875.17 with a p-value of 0.000, leading to the rejection of the null hypothesis that individual effects are uncorrelated with the explanatory variables at the 1% significance level. This suggests that the estimates obtained from the random effects model may be biased, whereas the fixed effects model provides more consistent and reliable estimates.

Based on the results of both the F-test and the Hausman test, this study ultimately adopts the fixed effects model for the subsequent empirical regression analysis, as it effectively controls for time-invariant unobserved individual heterogeneity that could otherwise bias the estimation results.

Table 12. *Model selection test*

Test methods	Null hypothesis	Statistic	p-value	Test results
F test	There are no individual effects (the mixed OLS model is superior to the fixed effects model).	F=12.78	0.000	Rejecting the null hypothesis, a fixed effects model should be chosen.
Hausman test	Individual effects are not correlated with explanatory variables (random effects models are superior to fixed effects models).	$\chi2$=875.17	0.000	Rejecting the null hypothesis, a fixed effects model should be chosen.

To examine the overall effect of the Green Credit Guidelines on green innovation among heavily polluting firms, this study conducts a baseline regression analysis, with the results reported in Table 13.

Columns (1), (3), and (5) of Table 13 present the regression results without the inclusion of control variables. The results show that the coefficient of the core explanatory variable, Post*Treat is significantly positive at the 1% level when green patent applications in total (Patent_total), green invention patents (Patent_inv), and green utility model patents (Patent_noninv) are used as the dependent variables. These findings provide preliminary evidence that the implementation of the green credit policy has significantly promoted green technological innovation activities among heavily polluting firms.

After gradually adding a series of control variables such as firm size and profitability (ROA), columns (2), (4), and (6) show the complete regression results. In column (2), the coefficient of Post*Treat is 0.1664 and is significant at the 1% level. This result strongly supports the research hypothesis H1, that is, green credit policies constitute an effective external driving force forcing heavily polluting enterprises to carry out green innovation by increasing the cost of environmental violations and releasing positive signals.

To further explore the differences in the impact of policies on different types of green innovation, this paper distinguishes between innovation quality. Column (4) shows that Post*Treat has a coefficient of 0.0548 for high-quality green invention patents (Patent_inv), which is significant at the 1% level. Column (6) shows that Post*Treat has a coefficient of 0.1765 for green utility model patents (Patent_noninv), which have relatively low technological content, also significant at the 1% level. By comparing the coefficients, it can be found that the policy's promoting effect on green utility model patents (0.1765) is much greater than its promoting effect on green invention patents (0.0548). That is, although green credit policies generally incentivize green innovation in enterprises, their effect is more reflected in the quantity and "strategic" utility model innovations, while the driving force for fundamental, high quality invention innovations is relatively weak. This may be because when facing external environmental pressures, enterprises tend to choose utility model patents, which require less investment, have shorter cycles, and lower risks, to quickly meet compliance requirements or gain reputation, rather than engaging in long-term, disruptive technological research and development.

From the perspective of corporate innovation behavior, this result may reflect a strategic choice in patent layout by enterprises under the incentive of green credit policies. That is, enterprises may not necessarily prioritize high-quality, groundbreaking green technology innovation, but are more likely to respond to policy requirements and financing assessments through more easily implemented, lower-cost, and faster-return innovation forms. Compared to invention patents, utility model patents typically require less R&D investment, have lower technical barriers, relatively simpler application processes, and shorter authorization cycles, enabling the formation of quantifiable innovation results in a shorter time. This characteristic makes them more suitable as a tool for enterprises to demonstrate their innovation activity and green transformation achievements to banks, regulatory authorities, or capital markets. Incentivized by green credit policies, some enterprises, needing to alleviate financing constraints, improve credit availability, and enhance external evaluation performance, may be more inclined to pursue utility model patents rather than invention patents, which have longer investment cycles and higher uncertainties.

Furthermore, this phenomenon reflects a possible "strategic innovation" or even "quantity bias" in corporate green innovation behavior. The original intention of green credit policies was to guide resources towards innovation activities that truly have technological advancement and environmental improvement effects. However, in practice, if financial institutions or external evaluation systems place more emphasis on explicit indicators such as the number of patents, companies may adaptively adjust their strategies based on these evaluation criteria. They may allocate more innovation resources to utility model patents, which are easier to produce results in the short term, rather than invention patents, which require higher long-term R&D investment and have more advanced technology. Therefore, while green credit policies generally increase the quantity of green technology innovation by companies, they may not simultaneously promote a substantial improvement in the quality of innovation. This also illustrates that corporate innovation behavior is not entirely driven by the logic of technological progress, but rather exhibits clear instrumental rationality characteristics under the combined influence of policy incentives, financing needs, and performance pressures.

From the results of the control variables, the model results generally conform to theoretical expectations. Firm size (Size) is significantly positive in all three regression groups, indicating that larger firms have advantages in capital, technology, and organizational resources, and are more capable of carrying out green technology innovation. The coefficient of profitability (ROA) is generally positive, indicating that firms with better operating performance are more capable of undertaking green R&D investment. ListAge has a significant negative impact on the total number of green patents and green invention patents, suggesting that firms with longer establishment or listing histories may have a certain path dependence in their innovation activities, thus inhibiting high-quality green innovation; however, its impact on green non-invention patents is not significant. The debt-to-equity ratio (Lev) has a significant positive impact on green non-invention patents, a weakly significant positive impact on the total number of green patents, but no significant impact on green invention patents, suggesting that moderate debt may be more conducive to supporting firms to carry out relatively low-risk, quick-return green innovation activities. Firm growth (Growth) has a significant negative impact on the total number of green patents and green invention patents, indicating that firms under greater growth pressure may focus more on short-term operating goals, thus inhibiting green R&D investment. The shareholding ratio of the largest shareholder (Top1_Share) was significantly negative in all three models, indicating that excessive concentration of equity may weaken the long-term innovation incentives of enterprises and is not conducive to the development of green technology innovation activities.

Table 13. *Baseline Regression results analysis*

	(1) Patent_total	(2) Patent_total	(3) Patent_inv	(4) Patent_inv	(5) Patent_noninv	(6) Patent_noninv
Post*Treat	0.1315***	0.1664***	0.0342**	0.0548***	0.1523***	0.1765***
	(0.0045)	(0.0064)	(0.0053)	(0.0084)	(0.0176)	(0.0187)
Size		0.2672***		0.2163***		0.2793***
		(0.0061)		(0.0052)		(0.0054)
ROA		0.1635***		0.0974**		0.1682***
		(0.0782)		(0.0173)		(0.0523)
ListAge		-0.0183**		-0.0365***		0.0159
		(0.0075)		(0.0056)		(0.0057)
Lev		0.0556*		0.0072		0.0723***
		(0.0172)		(0.0037)		(0.0141)
Growth		-0.0228**		-0.0192***		-0.0036
		(0.0073)		(0.0065)		(0.0062)
Top1_Share		-0.1415***		-0.0782**		-0.1424***
		(0.0237)		(0.0271)		(0.0282)
constant	1.5742***	-4.2453***	1.1145***	-5.1124***	0.4528***	-5.3375***
	(0.0134)	(0.1485)	(0.0143)	(0.1273)	(0.0145)	(0.1183)
N	53536	53536	53536	53536	53536	53536
Firm_FE	Yes	Yes	Yes	Yes	Yes	Yes
Year_FE	Yes	Yes	Yes	Yes	Yes	Yes
r2_a	0.6136	0.6672	0.5784	0.5892	0.5680	0.5874
F	68.7785	251.7784	4.5383	183.1675	152.5458	168.7231

*Note: Robust standard errors in parentheses; *** p <0.01, **p <0.05, *p<0.1*

3.2.5 Robustness Analysis

1. PSM-DID test

The "Green Credit Guidelines" primarily target heavily polluting industries, whose enterprise characteristics may differ systematically from those in non-heavily polluting industries, potentially leading to sample selection bias. To mitigate this issue, this paper first employs a propensity score matching and difference-in-differences (PSM-DID) approach for testing. We use a series of observable variables, such as firm size and profitability, as covariates in a Logit regression to match the treatment group with the control group firms whose characteristics are most similar.

The covariate balance test illustrated in Figure 14 shows that, after matching, the standardized biases of most covariates between the treatment and control groups are substantially reduced, and the distributions of propensity scores for the two groups become highly similar. These results indicate that the matching procedure is effective and that the PSM-DID approach is appropriate for addressing potential sample selection bias in this study.

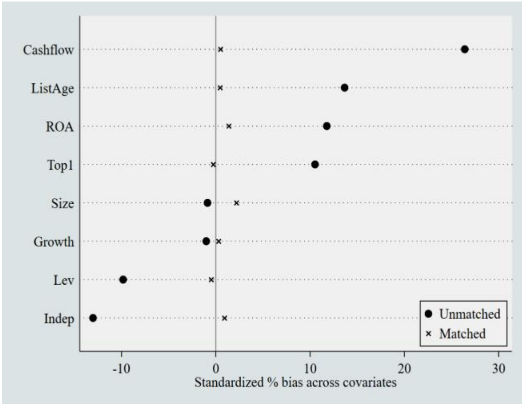


Figure 14. *Standardized Deviation Plot*

Table 14 reports the regression results after propensity score matching. The Post*Treat coefficient is significantly positive in Columns (1) and (3), while its statistical significance is relatively weaker in Column (2). Overall, these results are consistent with those of the baseline regressions, indicating that the main findings are robust and are not driven by sample selection bias. This further supports the research hypotheses proposed in this study.

Table 14. *PSM-DID test results*

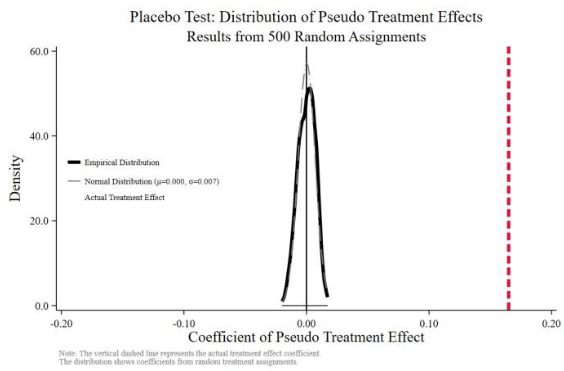
	Patent_total	**Patent_inv**	**Patent_noninv**
Post*Treat	0.1945***	0.0852***	0.1968***
	(0.0266)	(0.0252)	(0.0253)
Size	0.2618***	0.2175***	0.2239***
	(0.0164)	(0.0151)	(0.0153)
ROA	0.1428*	0.1384	0.1655***
	(0.0477)	(0.0393)	(0.0386)
ListAge	-0.0383***	-0.0264***	-0.0435*
	(0.0214)	(0.0087)	(0.0128)
Lev	0.0622*	0.0225	0.0782***
	(0.0225)	(0.0184)	(0.0226)
Growth	-0.0182**	-0.0165*	-0.0294
	(0.0075)	(0.0081)	(0.0083)
Top1_Share	-0.1285**	-0.0722*	-0.1191***
	(0.0484)	(0.0456)	(0.0502)
constant	5.6327***	11.3556***	-7.5783***
	(0.1184)	(0.1825)	(0.1545)
N	38163	38163	38163
Firm_FE	Yes	Yes	Yes
Year_FE	Yes	Yes	Yes
r2_a	0.6683	0.6235	0.5992
F	148.5835	102.2726	113.6847

*Note: Robust standard errors in parentheses; *** p <0.01, **p <0.05, *p<0.1*

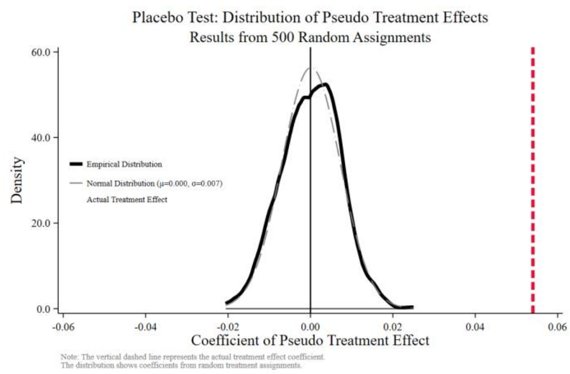
2.Placebo test

To further rule out the possibility that the research findings are driven by other unobserved time-varying factors or purely random shocks, this study conducts a placebo test. Specifically, firms equal in number to the actual heavily polluting firms are randomly selected from the full sample as a fictitious "treatment group," while the remaining firms are assigned to a fictitious "control group," and the baseline Post*Treat regression is then estimated. This random sampling procedure is repeated 500 times, yielding 500 estimates of placebo policy effects.

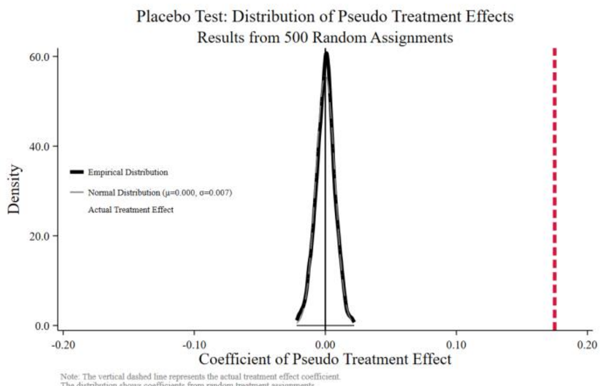
Figure 15 plots the kernel density distribution of these 500 estimated coefficients. As shown, these randomly generated coefficients are highly concentrated around 0, exhibiting an approximately normal distribution, and are not statistically significant at the 10% significance level. The actual treatment effects (the baseline regression coefficients for Patent_total, Patent_inv, and Patent_noninv are 0.1664, 0.0548, and 0.1765, respectively) lie outside the distribution of the pseudo-treatment effects, indicating that the actual effects are significantly higher than the random effects distribution. This suggests that the impact of green credit policies on corporate green technology innovation is not driven by unobservable random factors, but rather represents a genuine and effective intervention. The red dashed line represents the upper bound of the pseudo-treatment effect distribution, used to assess whether there is a significant deviation.



（a）Total Green Patents



(b) Green Invention Patent



(C) Green Utility Patent

Figure 15. *Placebo test*

3. Narrow the time window

Considering that the COVID-19 pandemic, which began in 2020, may have exerted substantial shocks on the global economy and corporate activities, this study re-estimates the model after excluding the sample period from 2020 to 2024. The results reported in Table 15 show that the significance of the Post*Treat coefficient does not change materially, indicating that the main findings are robust to the exclusion of the COVID-19 period.

Table 15. *Robustness analysis after removing the impact of the epidemic(2007-2019)*

	(1) **Patent_total**	(2) **Patent_inv**	(3) **Patent_noninv**
Post*Treat	0.1714***	0.1086***	0.1832***
	(0.0225)	(0.0203)	(0.0214)
Size	0.1896***	0.1682***	0.1795***
	(0.0118)	(0.0097)	(0.0105)
ROA	0.1298***	0.0874***	0.1435***
	(0.0475)	(0.0356)	-(0.0462)
ListAge	-0.0145	-0.0117	0.0125
	(0.0068)	(0.0046)	(0.0053)
Lev	0.1125*	0.1173***	0.1739***
	(0.0182)	(0.0165)	(0.0128)
Growth	-0.0235***	-0.0216	-0.0154
	(0.0093)	(0.0088)	(0.0086)
Top1_Share	-0.0782**	-0.0675***	-0.0892***
	(0.0264)	(0.0186)	(0.0215)
constant	-6.3175***	-8.4727***	-5.1163***
	(0.1184)	(0.1162)	(0.1064)
N	41773	41773	41773
Firm_FE	Yes	Yes	Yes
Year_FE	Yes	Yes	Yes
r2_a	0.6672	0.5685	0.5716
F	150.3386	110.2645	109.3872

*Note: Robust standard errors in parentheses; *** p <0.01, **p <0.05, *p<0.1*

In conclusion, after a series of comprehensive robustness tests, including parallel trend tests, PSM-DID, placebo tests, and narrowing the time window, the implementation of the "Green Credit Guidelines" has significantly promoted green innovation in heavily polluting enterprises, and the core conclusion that "this promotion effect has a greater incentive for quantitative innovation (utility models) than for qualitative innovation (invention patents)" has been proven to be robust.

4.Endogeneity Test

The impact of green credit policies on green innovation in manufacturing enterprises typically exhibits a certain lag. To avoid endogeneity issues caused by reverse causality, this study tested the dependent variable (green technology innovation) using a one-lag and a two-lag approach. Column (1) of Table16 reports the regression results with a one-lag, where the estimated coefficient of the interaction term (Post×treat) is 0.1437, significantly positive at the 1% significance level. Column (2) reports the regression results with a two-lag, where the estimated coefficient of the interaction term (Post×treat) is 0.1365, also significantly positive at the 1% significance level. The results indicate that green credit policies have a significant lagged promoting effect on green innovation in manufacturing enterprises, further validating the robustness of the baseline regression results.

Table 16. *Endogeneity Test*

	(1) Patent_total	**(2)** Patent_total
Post*Treat	0.1437***	0.1365***
	(0.0174)	(0.0168)
Size	0.1625***	0.1593***
	(0.0096)	(0.0085)
ROA	0.1076***	0.0901***
	(0.0389)	(0.0270)
ListAge	-0.0128**	-0.0096**
	(0.0059)	(0.0051)
Lev	0.0936***	0.0845***
	(0.0173)	(0.0170)
Growth	-0.0186***	-0.0143***
	(0.0085)	(0.0083)
Top1_Share	-0.0654**	-0.0582**
	(0.0253)	(0.0247)
constant	-4.1892***	-2.5136***
	(0.2136)	(0.1985)
N	48642	43971
Firm_FE	Yes	Yes
Year_FE	Yes	Yes
r2_a	0.6438	0.6172
F	97.2573	75.3641

*Note: Robust standard errors in parentheses; *** p <0.01, **p <0.05, *p<0.1*

3.2.6 Mediator Regression Analysis

The preceding analysis confirms the net effect of the Green Credit Guidelines on green innovation among heavily polluting firms. However, the specific micro-level channels through which this macro-level policy operates remain to be further explored. To open the "black box" of policy impact, this section examines three potential transmission mechanisms: financing constraints, environmental information disclosure, and government subsidies. The estimation results are reported in Table 17.

The results in column (1) of Table 17 provide direct evidence for this. The regression coefficient of the core explanatory variable Post*Treat on financing constraints (FC) is -0.2183, which is significantly positive at the 1% level. This indicates that green credit can effectively alleviate the financing pressure on enterprises, especially if enterprises are engaged in green projects, they can enjoy preferential loan interest rates for green credit and reduce their own financing costs. In column (2) of Table 17, the regression coefficient of green credit policy on green technology innovation of enterprises in the mechanism test model is 0.1418, which is significant at the 1% level; the regression coefficient of financing constraints on green technology innovation of enterprises is -0.1125, which is also significant at the 1% level. This indicates that in the total effect of green credit on improving the green technology innovation capability of enterprises, part of the effect is achieved by reducing the financing costs of enterprises, and the hypothesis H3 mentioned above is verified.

In column (3) of Table 17, the coefficient of Post*Treat for Environmental Information Disclosure Quality (EIDQ) is 0.8654, which is significant at the 1% statistical level. This indicates that the policy significantly promotes heavily polluting enterprises to improve their environmental information disclosure level. In order to obtain green credit funding support, enterprises will pay more attention to environmental protection and energy conservation and actively and promptly disclose their own environmental information. In column (4) of Table 17, the regression coefficient of green credit policy on enterprise green technology innovation in the mechanism test model is 0.1063, which is significant at the 1% statistical level; the regression coefficient of enterprise environmental information disclosure level on enterprise green technology innovation is 0.0691, which is also significant at the 1% statistical level. This indicates that in the total effect of green credit on improving the level of enterprise green technology innovation, part of the effect is achieved through enterprise environmental information disclosure. By actively disclosing their own environmental information, improving the transparency of environmental information, and reducing environmental risks, enterprises can more easily obtain green credit funding support, and thus have sufficient funds for R&D activities of green technology innovation. The hypothesis H4 mentioned above is verified.

The results in column (5) of Table 17 provide empirical evidence for this. The coefficient of Post*Treat on corporate R&D intensity (rd_rate) is 0.0254, which is significantly positive at the 1% level, indicating that green credit policies significantly incentivize heavily polluting enterprises to increase their R&D investment. In column (6) of Table 17, the regression coefficient of green credit policy on corporate green technology innovation in the mechanism test model is 0.1482, which is significant at the 1% level; the regression coefficient of R&D intensity on corporate green technology innovation is 0.7152, which is also significant at the 1% level, indicating that R&D investment plays a partial mediating role between green credit policy and corporate green innovation, and the hypothesis H2 mentioned above is verified.

Table 17. *Mechanism Test*

	(1) **FC**	(2) **Patent_total**	(3) **EIDQ**	(4) **Patent_total**	(5) **RD_rate**	(6) **Patent_total**
Post*Treat	-0.2183***	0.1418***	0.8654***	0.1063***	0.0254**	0.1482***
	(0.0145)	(0.0154)	(0.0192)	(0.0184)	(0.0096)	(0.0165)
FC		-0.1125***				
		(0.0067)				
EIDQ				0.0691***		
				(0.0045)		
RD_rate						0.7152***
						(0.0099)
Size	0.2162***	0.2875***	0.6554***	0.1723***	0.3135***	0.3254***
	(0.0146)	(0.0093)	(0.0295)	(0.0155)	(0.0112)	(0.0171)
ROA	0.3893***	-0.0132	0.6794***	0.2163**	-0.5266***	0.3015***
	(0.0274)	(0.0045)	(0.0352)	(0.0314)	(0.0398)	(0.0452)
ListAge	-0.0438***	-0.0357***	0.8961***	-0.0382**	-0.2554***	-0.0263
	(0.0027)	(0.0093)	(0.0068)	(0.0085)	(0.0036)	(0.0091)
Lev	-0.3473***	0.0784*	-0.2875	0.0569*	-0.2494***	0.0690***
	(0.0215)	(0.0205)	(0.0193)	(0.0347)	(0.0282)	(0.0324)
Growth	-0.0136	-0.0259*	-0.1197*	-0.0218**	-0.3745***	-0.0109
	(0.0054)	(0.0046)	(0.0045)	(0.0063)	(0.0091)	(0.0040)
Top1_Share	-0.0782***	-0.0768***	-0.2178	-0.0293***	-0.0340***	-0.0765***
	(0.0177)	(0.0082)	(0.0093)	(0.0112)	(0.0074)	(0.0082)
constant	4.8674***	-7.2563***	-9.3185***	-6.4654***	3.1865***	-6.2983***
	(0.0356)	(0.0145)	(0.0846)	(0.1481)	(0.1187)	(0.1198)
N	53536	53536	53536	53536	53536	53536
Firm_FE	Yes	Yes	Yes	Yes	Yes	Yes
Year_FE	Yes	Yes	Yes	Yes	Yes	Yes
r2_a	0.7535	0.6237	0.5892	0.6174	0.6815	0.6286
F	324.6554	297.6183	236.7095	168.2170	128.6352	246.5234

*Note: Robust standard errors in parentheses; *** p <0.01, **p <0.05, *p<0.1*

Robustness test of the mediating effect

While the stepwise regression method initially verified the existence of each mediation mechanism, to overcome the potential for low statistical power and accurately quantify the relative importance of each channel in the overall effect, this paper further employs the

Bootstrap self-sampling method to conduct robustness tests with 1000 samplings and decompose the mediation effects.

According to the Bootstrap test results in the lower half of Table 18, the indirect effects of the three mechanism variables — financing constraints, environmental information disclosure, and R&D investment—do not contain 0 within the 95% confidence interval, and all have Z-values greater than 1.96 and P-values less than 0.05. Specifically, the indirect effect value of the financing constraint path is 0.0246, the indirect effect value of the environmental information disclosure path is 0.0601, and the indirect effect value of the R&D investment path is 0.0182. These results further confirm that the three transmission paths proposed in this paper are robust and effective.

To further examine the differences in contributions from different pathways, Table 19 reports the mediating effect percentages for each channel, calculated based on a total effect value of 0.1664. The results show that the mediating effect of environmental information disclosure quality is the highest among the three mechanisms, reaching 36.14%. This indicates that during the implementation of green credit policies, improving information transparency to alleviate information asymmetry between banks and enterprises is the primary channel for enterprises to obtain green credit support and thus promote innovation. In contrast, the mediating effects of financing constraints and R&D investment are 14.97% and 10.92%, respectively, which, although relatively low, are still significant. In conclusion, improving the quality of environmental information disclosure to gain external trust is the most important path for current policies to be effective.

Table 18. *Mediation Effect Test（Bootstrap）*

path	**Mediation effect**	**Bootstrapb S.E.**	**Z**	**p-value**	**95% confidence interval**	**Test results**
Post*Treat→FC→Patent_total	0.0246	0.0013	4.18	0.000	[0.0013, 0.0215]	Significant (interval does not contain 0)
Post*Treat→EIDQ→Patent_total	0.0601	0.0019	5.39	0.000	[0.0024, 0.0119]	Significant (interval does not contain 0)
Post*Treat→RD_rate→Patent_total	0.0182	0.0007	2.54	0.015	[0.0009, 0.0086]	Significant (interval does not contain 0)

*Note: Robust standard errors in parentheses; *** p <0.01, **p <0.05, *p<0.1*

Table 19. *Mediation effect proportion*

path	Mediation effect	Total effect	Mediation rate	Test results
Post*Treat→FC→Patent_total	0.0246	0.1664	14.97%	Partial mediation
Post*Treat→EIDQ→Patent_total	0.0601	0.1664	36.14%	Partial mediation
Post*Treat→RD_rate→Patent_total	0.0182	0.1664	10.92%	Partial mediation

*Note: Robust standard errors in parentheses; *** p <0.01, **p <0.05, *p<0.1*

3.2.7 Moderating Regression Analysis

To explore the heterogeneity of the effects of green credit policies, i.e., the boundary conditions under which they function, this section constructs a triple difference-of-differences (DDD) model to examine the moderating effects of key external environmental factors and internal governance characteristics on policy effects. The test results, shown in Table 20, clearly reveal that the innovation incentive effect of green credit policies is not homogeneous but is systematically influenced by specific contextual factors.

Specifically, in column (1), the regression coefficient of the core interaction term Post× Treat × Executive Financial Background is 0.1165, which is significant at the 1% level, indicating that when executives have a financial background, the promoting effect of green credit policies on corporate green technology innovation is further enhanced. This may be because executives with a financial background typically have a stronger understanding and grasp of financial policies, financing channels, and capital allocation methods, enabling them to more accurately identify financing opportunities and policy incentives brought about by green credit policies and more effectively transform them into green R&D investment and green innovation output. Therefore, the executives' financial background plays a positive reinforcing role, verifying the relevant moderating hypothesis.

In column (2), the regression coefficient of the interaction term Post × Treat × Institutional Shareholding is 0.5462, which is significant at the 1% level, indicating that the promotion effect of green credit policy on corporate green technology innovation is significantly enhanced as the proportion of institutional investor shareholding increases. Compared with the moderating coefficient of senior executives' financial background, the moderating effect of institutional shareholding ratio is stronger. This shows that institutional investors can enhance the responsiveness of enterprises to green credit policy through mechanisms such as external supervision, governance optimization, and improved resource allocation, thereby more effectively promoting green technology innovation.

From the perspective of the main effects, the coefficients of Post × Treat in the two columns are 0.1581 and 0.1734, respectively, and both are significantly positive, indicating that the positive impact of green credit policy on corporate green technology innovation remains robust after the addition of the moderating variable. This shows that the moderating effect further strengthens the policy impact on the basis of the main effect, rather than replacing the main effect.

Looking at the coefficients of the moderating variables themselves, the coefficient for executives with financial backgrounds is 0.0135, significant at the 1% level, indicating that executives with financial backgrounds themselves contribute to improving the level of corporate green innovation. The coefficient for institutional shareholding is 0.1245, significant at the 5% level, indicating that the higher the proportion of institutional investor shareholding, the higher the overall level of corporate green technology innovation. This further illustrates that a sound governance structure and stronger capital market supervision help companies carry out green innovation activities.

The results of the control variables are generally consistent with theoretical expectations. The coefficients for firm size and profitability (ROA) are both significantly positive, indicating that larger and more profitable companies are more capable of carrying out green technology innovation; the debt-to-equity ratio (Lev) is significantly positive, indicating that moderate debt may provide financing support for corporate innovation activities; the coefficient for growth is significantly negative, possibly indicating that companies under greater growth pressure tend to prioritize short-term operating goals, thus inhibiting investment in green innovation; the shareholding ratio of the largest shareholder (Top1) is significantly negative, indicating that excessive concentration of equity may be detrimental to corporate green technology innovation to some extent. The listing years (ListAge) is significantly negative only in column (1) and not significant in column (2), indicating that its impact is relatively limited.

Overall, the moderating effect analysis shows that the role of green credit policies in promoting green technology innovation in enterprises is influenced by the characteristics of senior executives and the external governance structure. Both the financial background of senior executives and the proportion of institutional shareholding significantly amplify this policy effect, with the amplifying effect of institutional shareholding being more pronounced. This indicates that to fully unleash the innovation incentive effect of green credit policies, it is necessary not only to improve the policy system but also to emphasize the optimization of corporate governance mechanisms and the enhancement of the capabilities of senior management teams.

Table 20. *Analysis of Moderating Effect Results*

	Patent_total（FinBack）	**Patent_total**（Lis）
Post*Treat	0.1581***	0.1734***
	(0.0180)	(0.0242)
Post*Treat×FinBack	0.1165***	
	(0.0193)	
FinBack	0.0135***	
	(0.0026)	
Post*Treat×Lis		0.5462***
		(0.0414)
Lis		0.1245**
		(0.0262)
Size	0.2285***	0.2394***
	(0.0132)	(0.0095)
ROA	0.1496***	0.1566***
	(0.0461)	(0.0387)
ListAge	-0.0210**	-0.0109
	(0.0054)	(0.0061)
Lev	0.1472**	0.1023**
	(0.0186)	(0.0267)
Growth	-0.0355**	-0.0288***
	(0.0134)	(0.0135)
Top1_Share	-0.1253***	-0.2164***
	(0.0286)	(0.0392)
Constant	-3.4557***	-4.9780***
	(0.3782)	(0.1591)
N	53536	53536
Firm_FE	Yes	Yes
Year_FE	Yes	Yes
r2_a	0.6393	0.6142
F	276.1345	168.2877

*Note: Robust standard errors in parentheses; *** p <0.01, **p <0.05, *p<0.1*

3.2.8 Heterogeneity Tests

1. Firm size heterogeneity

This paper, following international best practices (OECD), uses the number of employees as the basis for classifying enterprise size, dividing enterprises into micro (<10 employees), small (10 – 49 employees), medium (50 – 249 employees), and large (≥250 employees). Because the sample size of small enterprises is relatively small according to the above classification criteria, conducting separate grouped regression analysis might affect the stability and reliability of the estimation results. Therefore, this paper divides the sample enterprises into two groups: large enterprises and small and medium-sized enterprises, to further examine the differences in the impact of green credit policies on green technology innovation of enterprises of different sizes.

Table 21 shows that the impact of green credit policies on green technology innovation varies significantly across enterprises of different sizes. Overall, green credit policies significantly promote green technology innovation in large enterprises, but their effect on SMEs is not significant, and even shows an inhibitory effect on some indicators.

In the SME sample, the regression coefficients of the core explanatory variable Post × Treat for total green patents (Patent_total) and green invention patents (Patent_inv) are -0.0465 and -0.0304, respectively, both failing the significance test; the regression coefficient for green non-invention patents (Patent_noninv) is -0.0482, significantly negative at the 10% level. This indicates that green credit policies have not significantly promoted green technology innovation in SMEs, and may instead inhibit low-quality green innovation output to some extent. This may be because SMEs generally face problems such as weak capital strength, limited financing channels, insufficient collateral, and poor risk resistance. After the implementation of green credit policies, financial institutions pay more attention to environmental performance, information disclosure quality and repayment ability in lending. However, small and medium-sized enterprises (SMEs) often find it difficult to meet green financing requirements in a timely manner, thus facing higher financing thresholds to some extent, which inhibits green R&D investment and green innovation output.

In contrast, the promoting effect of green credit policies is significant in the sample of large enterprises. The regression coefficients of Post × Treat for the total number of green patents, green invention patents, and green non-invention patents are 0.3156, 0.2471, and

0.3368, respectively, all significantly positive at the 1% level. This indicates that green credit policies significantly enhance the level of green technology innovation in large enterprises, and not only promote the growth of the total number of green patents, but also significantly boost the output of green invention patents and green non-invention patents. Comparatively, the policy has the greatest promoting effect on green non-invention patents in large enterprises, followed by the total number of green patents and green invention patents. This suggests that, under policy incentives, large enterprises are more likely to simultaneously engage in incremental green innovation and high-quality green innovation activities. This may be because large enterprises typically possess stronger resource integration capabilities, more robust internal governance structures, higher levels of environmental information disclosure, and more ample R&D funding reserves, enabling them to more effectively identify and utilize the financing convenience and policy incentives brought by green credit policies, thereby transforming policy advantages into green innovation achievements.

Further comparison of the results for the two types of enterprises reveals that the innovation incentive effect of green credit policies exhibits a clear scale threshold characteristic. On the one hand, large enterprises, due to their stronger financing capabilities, higher credit levels, and greater information transparency, are more likely to obtain green credit support. On the other hand, although SMEs also face pressure for green transformation, they are constrained by financing limitations, weak technological foundations, and insufficient innovation investment, making it difficult for them to fully enjoy the benefits of green credit policies. Therefore, the promoting effect of green credit policies on green technology innovation in large enterprises is significantly stronger than that in SMEs.

From the perspective of control variables, firm size was significantly positive in both types of firm samples, indicating that larger firms, regardless of size, are more conducive to green technology innovation. Return on Assets (ROA) was significantly positive only in the large firm sample, suggesting that large firms are better able to translate operational performance into green innovation investment. List age was significantly positive in SMEs but not in large firms, possibly indicating that SMEs' innovation capabilities improve with accumulated experience. The shareholding ratio of the largest shareholder (Top1_Share) had a negative impact in large firms, particularly a weakly significant inhibitory effect on green non-invention patents, suggesting that excessive concentration of equity may be detrimental to the green innovation activities of large firms.

Overall, the firm size heterogeneity analysis indicates that the innovation incentive effect of green credit policies is mainly concentrated in large firms, while its effect on SMEs is limited or even somewhat inhibitory. This suggests that the implementation of green credit policies may exhibit a phenomenon of "resources tilting towards advantageous firms." Therefore, in promoting the implementation of green finance policies, more attention should be paid to the financing bottlenecks faced by SMEs in their green transformation. By improving green guarantee mechanisms, innovating green financial products, and strengthening policy support, we can enhance SMEs' ability to access green credit resources, thereby increasing the inclusiveness and effectiveness of green credit policies.

Table 21. *Analysis of Firm Size Heterogeneity Results*

	Small and medium-sized enterprises			**large-scale enterprises**		
	Patent_total	**Patent_inv**	**Patent_noninv**	**Patent_total**	**Patent_inv**	**Patent_noninv**
Post*Treat	-0.0465	-0.0304	-0.0482*	0.3156***	0.2471***	0.3368***
	(0.0081)	(0.0079)	(0.0080)	(0.0157)	(0.0146)	(0.0159)
Size	0.2062***	0.1385***	0.2271***	0.2763***	0.2185***	0.2490***
	(0.0123)	(0.0119)	(0.0125)	(0.0107)	(0.0092)	(0.0121)
ROA	0.0151	0.0092	0.0146	0.3165***	0.2671*	0.3484***
	(0.0036)	(0.0023)	(0.0038)	(0.0237)	(0.0206)	(0.0243)
ListAge	0.0375***	0.0304***	0.0419***	0.0265	0.0179	0.0301
	(0.0059)	(0.0051)	(0.0060)	(0.0072)	(0.0078)	(0.0081)
Lev	0.0527*	0.0601	0.0598*	-0.0786	-0.0681	-0.0982
	(0.0125)	(0.0119)	(0.0126)	(0.0069)	(0.0065)	(0.0070)
Growth	0.0115	0.0083	0.0123	-0.0067	-0.0058	0.0069
	(0.0042)	(0.0040)	(0.0047)	(0.0031)	(0.0029)	(0.0034)
Top1_Share	-0.0226	-0.0182	0.0259	-0.1042	-0.0901	-0.1273*
	(0.0059)	(0.0056)	(0.0061)	(0.0135)	(0.0108)	(0.0142)
Constant	-2.1651***	-2.0784***	-2.4176***	-5.1193***	-2.8119***	-4.2181***
	(0.2562)	(0.2085)	(0.2738)	(0.1236)	(0.0964)	(0.1347)
N	7058	7058	7058	46478	46478	46478
Firm_FE	Yes	Yes	Yes	Yes	Yes	Yes
Year_FE	Yes	Yes	Yes	Yes	Yes	Yes
r2_a	0.6278	0.6145	0.6337	0.6673	0.6538	0.6836
F	51.1396	47.2651	52.4562	96.7545	87.5234	103.2653

*Note: Robust standard errors in parentheses; *** p <0.01, **p <0.05, *p<0.1*

2.Heterogeneity in property rights

This article categorizes enterprises into state-owned enterprises (SOEs) and non-state-owned enterprises (NOEs) based on their ownership structure. SOEs, as key enterprises supported by the state, enjoy higher social recognition compared to NOEs. They bear social responsibility and need to cultivate a positive social image, thus placing greater emphasis on environmental performance. When facing environmental and social risks, they actively increase investment, enhance their innovation capabilities, and transition towards green development. Furthermore, SOEs experience less financing constraint during the credit process. Conversely, NOEs focus more on economic efficiency, investing primarily in production and operations, showing less inclination towards innovation. Moreover, the uncertainties associated with innovation are significantly greater for NOEs than for SOEs.

As shown in Table 22, the impact of green credit policies on green technology innovation of enterprises with different ownership structures varies significantly. Overall, green credit policies have a stronger and more comprehensive promoting effect on state-owned enterprises, while their promoting effect on non-state-owned enterprises is relatively limited.

In the sample of state-owned enterprises (SOEs), the regression coefficients of the core explanatory variable Post×Treat for the total number of green patents (Patent_total), green invention patents (Patent_inv), and green non-invention patents (Patent_noninv) were 0.2625, 0.1245, and 0.2588, respectively, all significantly positive at the 1% level. This indicates that the green credit policy significantly promoted green technology innovation in SOEs, increasing not only the total number of green patents but also driving the output of green invention patents and green non-invention patents. The promoting effect on the total number of green patents and green non-invention patents was relatively stronger, while the promoting effect on green invention patents, although slightly weaker, was still significant. This suggests that after the implementation of the green credit policy, SOEs were able to fully transform the policy dividends into green innovation achievements.

In contrast, the effect of green credit policies was significantly weaker in the non-state-owned enterprise (SOE) sample than in SOEs. The regression coefficients of Post×Treat for the total number of green patents and green invention patents were 0.0417 and -0.0383, respectively, both failing the significance test; only the regression coefficient for green non-invention patents was 0.0584, significantly positive at the 5% level. This indicates that green credit policies do not significantly promote green innovation in non-SOEs as a whole, only having a certain promoting effect on relatively low-threshold, quick-resulting green innovation activities such as green non-invention patents, while failing to provide significant incentives for high-quality green innovations such as green invention patents.

Further comparison reveals that the innovation incentive effect of green credit policies exhibits significant heterogeneity in terms of ownership structure. On the one hand, state-owned enterprises (SOEs) typically enjoy greater access to financing, higher credit ratings, and stronger policy responsiveness, making them more likely to obtain bank credit support and invest funds in green R&D activities after the implementation of green credit policies. On the other hand, SOEs also bear more policy-related tasks and social responsibilities, resulting in a stronger willingness for green transformation and greater pressure for environmental compliance, thus making them more likely to engage in green technology innovation under policy impetus. In contrast, non-state-owned enterprises generally face stronger financing constraints, information asymmetry, and insufficient collateral, and even with the introduction of green credit policies, their ability to obtain green financing support remains relatively limited, thereby weakening the policy's incentive effect on their green innovation.

From the perspective of control variables, firm size was significantly positive in both types of firm samples, indicating that larger firms have greater resource advantages in carrying out green technology innovation. Profitability (ROA) was significantly positive in the regression of total green patents and green non-invention patents for non-state-owned enterprises, but only significantly positive for green non-invention patents in state-owned enterprises, indicating that the supporting role of profitability in green innovation varies among different ownership types of firms. Firm growth showed a certain negative impact in both types of firms, suggesting that growth pressure may, to some extent, squeeze investment in green innovation. The shareholding ratio of the largest shareholder (Top1_Share) had a significant negative impact on the total number of green patents and green non-invention patents in state-owned enterprises, but not in non-state-owned enterprises, suggesting that excessive concentration of equity may be less conducive to the effective allocation of green innovation resources in state-owned enterprises.

Overall, the heterogeneity analysis of state-owned enterprises (SOEs) and non-state-owned enterprises (NSEs) indicates that the promoting effect of green credit policies on corporate green technology innovation is mainly reflected in SOEs, while the incentive effect on NSEs is relatively limited. This suggests that green credit policies may exhibit a certain "ownership bias" in practice, meaning that policy resources are more likely to flow to SOEs with higher credit ratings and stronger financing capabilities. Therefore, to further enhance the inclusiveness and effectiveness of green credit policies, efforts should be focused on alleviating financing barriers for NSEs in their green transformation, improving green guarantee mechanisms and information enhancement mechanisms, and strengthening the ability of NSEs to access green financial resources.

Table 22. *Analysis of Heterogeneity in Property Rights*

	State-owned Enterprises			**Non-state-owned Enterprises**		
	Patent_total	Patent_inv	Patent_noninv	Patent_total	Patent_inv	Patent_noninv
Post*Treat	0.2625***	0.1245***	0.2588***	0.0417	-0.0383	0.0584**
	(0.0032)	(0.0061)	(0.0065)	(0.0162)	(0.0146)	(0.0145)
Size	0.2865***	0.2120***	0.2592***	0.1964***	0.1625***	0.2016***
	(0.0285)	(0.0226)	(0.0254)	(0.0185)	(0.0078)	(0.0156)
ROA	0.1284	0.0854	0.2698**	0.1102**	0.0792	0.1278**
	(0.0121)	(0.0152)	(0.0126)	(0.0094)	(0.0090)	(0.0096)
ListAge	-0.0234	-0.0145	-0.0764	0.0551***	0.0335	0.0697***
	(0.0035)	(0.0043)	(0.0038)	(0.0083)	(0.0078)	(0.0091)
Lev	0.0786	0.0451	0.0845	0.0264	0.0192	0.0518**
	(0.0055)	(0.0074)	(0.0063)	(0.0095)	(0.0090)	(0.0092)
Growth	-0.1212	-0.1542**	-0.0374	-0.1428**	-0.0552	-0.0874**
	(0.0076)	(0.0065)	(0.0069)	(0.0091)	(0.0108)	(0.0112)
Top1_Share	-0.3697**	-0.2997	-0.2815***	-0.1920	-0.1254	-0.0973
	(0.0742)	(0.0954)	(0.0265)	(0.0134)	(0.0153)	(0.0128)
Constant	-3.5125***	-2.7792***	-4.6546***	-3.1150***	-4.2465***	-5.1636***
	(0.1076)	(0.1045)	(0.1193)	(0.1046)	(0.0825)	(0.0951)
N	19604	19604	19604	33932	33932	33932
Firm_FE	Yes	Yes	Yes	Yes	Yes	Yes
Year_FE	Yes	Yes	Yes	Yes	Yes	Yes
r2_a	0.6268	0.6073	0.6574	0.6107	0.5366	0.5584
F	238.3182	169.2765	321.0781	126.5384	96.2435	98.6772

*Note: Robust standard errors in parentheses; *** p <0.01, **p <0.05, *p<0.1*

3. Industry Heterogeneity

（1）Heterogeneity Analysis between Manufacturing and Non-Manufacturing Industries

This article classifies the sample enterprises into industries based on the latest national standard "National Industrial Classification of Economic Activities" (GB/T 4754—2017) issued by the National Bureau of Statistics. Among them, the manufacturing industry mainly includes 30 industries such as agricultural and sideline food processing, food manufacturing, wine, beverage and refined tea manufacturing, tobacco products manufacturing, textile industry, furniture manufacturing, and pharmaceutical manufacturing (see Table 23); the remaining industries are classified as non-manufacturing.

Table 23. *Manufacturing Sector Codes and Names*

Code	Industry	Code	Industry
C13	Agricultural and sideline food processing industry	C28	Chemical fiber manufacturing industry
C14	Food manufacturing industry	C29	Rubber and plastic products industry
C15	Wine, beverage and fine tea manufacturing	C30	Non-metallic mineral products industry
C16	Tobacco Products Industry	C31	Ferrous metal smelting and rolling processing industry
C17	Textile industry	C32	Non-ferrous metal smelting and rolling processing industry
C18	Textile and apparel industry	C33	Metal products industry
C19	Leather, fur, feathers and their products and footwear industry	C34	General equipment manufacturing
C20	Timber processing and wood, bamboo, rattan, palm and grass products industry	C35	Specialized equipment manufacturing industry
C21	Furniture manufacturing	C36	Automobile manufacturing
C22	Paper and paper products industry	C37	Railway, shipbuilding, aerospace and other transportation equipment manufacturing
C23	Printing and Recorded Media Reproduction Industry	C38	Electrical machinery and equipment manufacturing
C24	Manufacturing of cultural, educational, arts and crafts, sports and entertainment products	C39	Computer, communication and other electronic equipment manufacturing industry
C25	Petroleum processing, coking and nuclear fuel processing industries	C40	Instrumentation Manufacturing
C26	Chemical raw materials and chemical products manufacturing industry	C41	Other manufacturing industries
C27	Pharmaceutical manufacturing	C42	Waste resource comprehensive utilization industry

Data source: National Bureau of Statistics of China

The results in Table 24 show that the impact of green credit policies on corporate green technology innovation varies significantly across different industries, with the overall effect being more pronounced on manufacturing enterprises.

First, in the sample of manufacturing enterprises, the core explanatory variable Post×Treat showed a significant positive impact on all three types of innovation indicators. Specifically, the regression coefficient for the total number of green patents (Patent_total) was 0.2794, significant at the 1% level; the regression coefficient for green invention patents (Patent_inv) was 0.1863, also significant at the 1% level; and the regression coefficient for green non-invention patents (Patent_noninv) was 0.2850, also significant at the 1% level. This indicates that green credit policies significantly promoted green technology innovation in manufacturing enterprises, resulting in a marked increase in both high-quality invention patents and non-invention patents. This may be because manufacturing enterprises typically have higher energy consumption and environmental pollution levels, are more significantly constrained by green credit policies, and are more inclined to achieve transformation and upgrading through green technology innovation.

Secondly, the promoting effect of green credit policies is relatively weak among non-manufacturing enterprises. Specifically, the coefficient of Post×Treat for total green patents (Patent_total) is 0.1482, significant only at the 10% level; the coefficient for green invention patents (Patent_inv) is 0.1045, but it did not pass the significance test; and the coefficient for green non-invention patents (Patent_noninv) is 0.1564, significant at the 10% level. This indicates that the incentive effect of green credit policies on green technology innovation in non-manufacturing enterprises is relatively limited, especially in promoting high-quality green invention patents. This may be because non-manufacturing enterprises have lower overall pollution emission levels, are less constrained by green credit policies, and therefore have relatively insufficient motivation for green innovation.

From the results of the control variables, firm size (Size) is significantly positive in both types of firms, indicating that larger firms have a greater resource advantage in carrying out green technology innovation. Profitability (ROA) is significantly positive for the total number of green patents and green non-invention patents in the manufacturing sector, and significantly positive for all three types of green innovation indicators in the non-manufacturing sector, indicating that strong profitability helps firms support green innovation activities. ListAge is significantly negative in the manufacturing sector, but significantly positive in the non-manufacturing sector, suggesting that different types of firms may have differences in their development stages and innovation paths. The shareholding ratio of the largest shareholder (Top1_Share) has a certain inhibitory effect on green innovation in the manufacturing sector, but the effect is not significant in the non-manufacturing sector, indicating that the constraint of equity concentration on the allocation of green innovation resources in manufacturing firms may be more pronounced.

Overall, the effect of green credit policies on promoting green technology innovation is more significant in manufacturing enterprises, while the policy effect is relatively weak in non-manufacturing enterprises. This result indicates that in practice, green credit policies mainly guide enterprises to increase investment in green technology research and development by imposing financing constraints and incentives on high-pollution and high-energy-consuming industries, thereby promoting the green transformation and upgrading of the manufacturing industry.

Table 24. *Heterogeneity Analysis：Manufacturing vs Non-Manufacturing*

	Manufacturing Enterprises			**Non-Manufacturing Enterprises**		
	Patent_total	Patent_inv	Patent_noninv	Patent_total	Patent_inv	Patent_noninv
Post*Treat	0.2794***	0.1863***	0.2850***	0.1482*	0.1045	0.1564*
	(0.0261)	(0.0212)	(0.0145)	(0.0132)	(0.0261)	(0.0345)
Size	0.1845***	0.1373***	0.2186***	0.2018***	0.1445***	0.2136***
	(0.0152)	(0.0145)	(0.0151)	(0.0146)	(0.0118)	(0.0132)
ROA	0.2143**	0.1134	0.2785**	0.0895**	0.0652**	0.1185**
	(0.0072)	(0.0056)	(0.0082)	(0.0123)	(0.0115)	(0.0130)
ListAge	-0.0346**	-0.0215*	-0.0455**	0.0623**	0.0553**	0.0712***
	(0.0091)	(0.0048)	(0.0089)	(0.0134)	(0.0109)	(0.0146)
Lev	0.0430**	0.0392	0.0688**	0.0191	0.0118	0.0471**
	(0.0075)	(0.0090)	(0.0085)	(0.0026)	(0.0015)	(0.0020)
Growth	-0.0893	-0.0781**	-0.1207	-0.1215**	-0.0628	-0.1052**
	(0.0132)	(0.0120)	(0.0116)	(0.0096)	(0.0075)	(0.0088)
Top1_Share	-0.1183**	-0.2032	-0.2174***	-0.1762	-0.1326	-0.1052
	(0.0356)	(0.0263)	(0.0265)	(0.0075)	(0.0067)	(0.0074)
Constant	-7.2874***	-3.2164***	-1.8961***	-2.6157***	-2.2643***	-5.6125***
	(0.2247)	(0.1655)	(0.0182)	(0.1168)	(0.1095)	(0.1161)
N	37582	37582	37582	15954	15954	15954
Firm_FE	Yes	Yes	Yes	Yes	Yes	Yes
Year_FE	Yes	Yes	Yes	Yes	Yes	Yes
r2_a	0.6156	0.6292	0.6485	0.6074	0.5862	0.5752
F	112.9248	98.7255	89.3546	127.6871	78.6583	92.5545

*Note: Robust standard errors in parentheses; *** p <0.01, **p <0.05, *p<0.1*

(2) Heterogeneity of capital intensity

Capital intensity reflects the relative importance of capital input to labor input in an industry's production process. Referring to the industry classification standards of the National Bureau of Statistics of China and existing research, this paper classifies sample enterprises into capital-intensive and labor-intensive industries based on their capital input characteristics. Capital-intensive industries typically feature large-scale fixed asset investment and high equipment dependence, while labor-intensive industries rely primarily on labor input with relatively low capital investment. Therefore, this paper uses the median fixed assets per capita in each year's sample industries as the threshold, defining industries above the median as high capital-intensive industries and those below as low capital-intensive industries.

Table 25 shows that the impact of green credit policies on green technology innovation varies significantly among enterprises with different capital intensities. Overall, green credit policies significantly promote green technology innovation in highly capital-intensive enterprises, but have little effect on low-capital-intensive enterprises, and even exhibit an inhibitory effect on green invention patents.

In the sample of low-capital-intensive enterprises, the regression coefficients of the core explanatory variable Post×Treat for total green patents (Patent_total) and green non-invention patents (Patent_noninv) are -0.0408 and 0.0107, respectively, both failing the significance test; the regression coefficient for green invention patents (Patent_inv) is -0.0882, and is significantly negative at the 1% level. This indicates that green credit policies have not significantly promoted green technology innovation in low-capital-intensive enterprises, but rather have, to some extent, inhibited their high-quality green innovation output. The possible reason is that low capital-intensive enterprises are usually mainly engaged in labor input and daily operations, with less fixed asset investment and relatively limited demand for technological transformation and equipment upgrades. Therefore, green credit policies are less compatible with their production and operation characteristics.

In contrast, the promoting effect of green credit policies is very significant in the sample of highly capital-intensive enterprises. The regression coefficients of Post×Treat for the total number of green patents, green invention patents, and green non-invention patents are 0.3556, 0.1945, and 0.3224, respectively, all significantly positive at the 1% level. This indicates that green credit policies significantly improve the level of green technology innovation in highly capital-intensive enterprises and have a significant incentive effect on the total number of green patents, green invention patents, and green non-invention patents. The promoting effect on the total number of green patents is the strongest, followed by green non-invention patents and green invention patents. This suggests that under the influence of policies, highly capital-intensive enterprises can not only increase the quantity of green innovations but also improve the output of high-quality green innovations to a certain extent.

From the perspective of control variables, firm size (Size) is significantly positive in both types of firms, indicating that larger firms have a stronger resource base for green technology innovation. Profitability (ROA) is significantly positive in high capital-intensive firms but not in low capital-intensive firms, suggesting that profitability provides stronger support for green innovation in high capital-intensive firms. List age has a negative impact on green invention patents in both types of firms, indicating that increased firm maturity may weaken the motivation for high-quality green innovation to some extent. The shareholding ratio of the largest shareholder (Top1_Share) is significantly negative for green non-invention patents in high capital-intensive firms, suggesting that excessive concentration of equity may be detrimental to the allocation of green innovation resources.

Table 25. *Heterogeneity Analysis of Capital Intensity*

	Low capital intensity			**High capital intensity**		
	Patent_total	Patent_inv	Patent_noninv	Patent_total	Patent_inv	Patent_noninv
Post*Treat	-0.0408	-0.0882***	0.0107	0.3556***	0.1945***	0.3224***
	(0.0054)	(0.0073)	(0.0075)	(0.0150)	(0.0272)	(0.0185)
Size	0.3526***	0.2791***	0.2064***	0.2492***	0.1845***	0.1708***
	(0.0112)	(0.0115)	(0.0126)	(0.0217)	(0.0184)	(0.0165)
ROA	0.0258	-0.0087	0.0853	0.3425***	0.2326**	0.2510***
	(0.0054)	(0.0029)	(0.0062)	(0.1107)	(0.0971)	(0.0874)
ListAge	-0.0142	-0.0386***	0.0211	-0.0342	-0.0484**	-0.0113
	(0.0080)	(0.0073)	(0.0089)	(0.0125)	(0.0107)	(0.0105)
Lev	0.1207**	0.0860*	0.0845*	-0.0156	-0.0518	0.0406
	(0.0295)	(0.0175)	(0.0267)	(0.0066)	(0.0114)	(0.0123)
Growth	-0.0176	-0.0171	-0.0082	-0.0038	-0.0137*	0.0109
	(0.0038)	(0.0015)	(0.0043)	(0.0014)	(0.0019)	(0.0020)
Top1_Share	-0.0391	-0.0356	0.0493	-0.2023	-0.1120	-0.2745***
	(0.0065)	(0.0059)	(0.0062)	(0.0045)	(0.0036)	(0.0041)
Constant	-7.2874***	-3.2164***	-1.8961***	-2.6157***	-2.2643***	-5.6125***
	(0.2247)	(0.1655)	(0.1382)	(0.2368)	(0.1295)	(0.1162)
N	26739	26739	26739	26797	26797	26797
Firm_FE	Yes	Yes	Yes	Yes	Yes	Yes
Year_FE	Yes	Yes	Yes	Yes	Yes	Yes
r2_a	0.6190	0.5693	0.5462	0.6657	0.6208	0.6115
F	44.3381	32.4054	25.8134	29.4842	19.6030	27.9492

*Note: Robust standard errors in parentheses; *** p <0.01, **p <0.05, *p<0.1*

Analysis Results

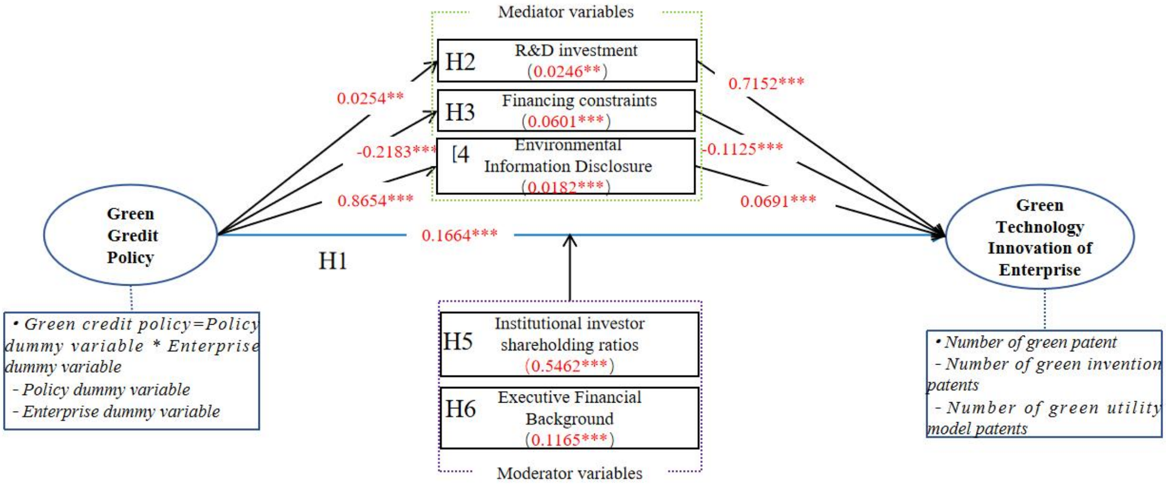


Figure 16. *Results of the research hypothesis*

Source:Developed by author

The results of the hypothesis testing show that green credit policies have both a direct and indirect promoting effect on corporate green technology innovation, transmitted through mediating variables, and are also influenced by the moderating effect of corporate governance characteristics, forming a complete action path of "direct effect—mediating mechanism—moderating mechanism".

First, regarding the direct effect, the direct impact coefficient of green credit policies on corporate green technology innovation is 0.1664, indicating that green credit policies can significantly improve the level of corporate green technology innovation, verifying the main effect hypothesis H1. This shows that, after controlling for other factors, green credit policies themselves already have a significant innovation incentive effect.

Secondly, regarding the mediation effect, the figure sets three mediating variables, and all three mediation paths are significant, indicating that green credit policies do not work through a single path, but rather promote corporate green technology innovation through multiple mechanisms. Firstly, the impact coefficient of green credit policies on R&D investment is 0.0255, and the impact coefficient of R&D investment on corporate green technology innovation is 0.7152, with the mediating effect shown in parentheses as 0.0246. This indicates that green credit policies can further promote green technology innovation by increasing corporate R&D investment levels, thus supporting H2. Secondly, the impact coefficient of green credit policies on financing constraints is -0.2183, and the impact coefficient of financing constraints on green technology innovation is -0.1125, with a mediating effect value of 0.0601. This shows that green credit policies can promote green technology innovation by alleviating corporate financing constraints, and from the perspective of the mediating effect value, this path has the strongest effect, thus supporting H3. Third, the impact coefficient of green credit policy on environmental information disclosure is 0.8654, the impact coefficient of environmental information disclosure on green technology innovation is 0.0691, and the mediating effect value is 0.0182. This indicates that green credit policy can also promote green technology innovation by improving the level of corporate environmental information disclosure, improving the external information environment and social supervision effect of enterprises, thus supporting H4.

Furthermore, since the overall effect of green credit policy on green technology innovation (0.1664) remains significant after including the three mediating variables, it can be concluded that these three variables play a partial, rather than a complete, mediating role. In other words, green credit policy not only directly affects corporate green technology innovation but also indirectly exerts its influence through three mechanisms: increasing R&D investment, alleviating financing constraints, and improving environmental information disclosure.

Finally, regarding the moderating effect, both moderating variables in the figure show significant positive moderating effects. The moderating effect coefficient for the institutional investor shareholding ratio is 0.5462, indicating that as the institutional investor shareholding ratio increases, the promoting effect of green credit policies on corporate green technology innovation will be further enhanced; this means that institutional investors can improve policy transmission efficiency by strengthening supervision, improving governance, and optimizing resource allocation. The moderating effect coefficient for the financial background of senior executives is 0.1165, indicating that when senior executives have a financial background, they are more able to accurately understand the signals of green credit policies, improve the efficiency of financing decisions, and optimize the allocation of green investments, thereby enhancing the promoting effect of green credit policies on corporate green technology innovation. In comparison, the moderating effect of the institutional investor shareholding ratio is stronger.

Overall, the figure shows that green credit policies have a significant promoting effect on corporate green technology innovation. The mechanism of this effect is mainly reflected in the R&D investment effect, the financing constraint mitigation effect, and the environmental information disclosure effect, while also being positively reinforced by the proportion of institutional investor shareholding and the financial background of senior management. This indicates that the effectiveness of green credit policies depends not only on the policy itself but also on the company's internal governance structure and management characteristics.

Table 8 Research hypothesis testing results

Hypothesis	Hypothesis Statement	Support or not
H1	Green credit policy can significantly promote green technology innovation in enterprises.	Supported
H2	Green credit policy can promote corporate green technological innovation by boosting R&D investment intensity.	Supported
H3	Green credit policy can improve the efficiency of green technology innovation in listed companies by alleviating financing constraints.	Supported
H4	Green credit policy can promote green technology innovation by improving companies' environmental information disclosure level.	Supported
H5	Institutional investor shareholding ratios positively moderate the relationship between green credit policy and corporate green technology innovation.	Supported
H6	Executives' financial background positively moderates the effect of green credit policies on promoting corporate green technology innovation.	Supported

Source:Developed by author

Summary: Chapter 3

Through empirical analysis, this chapter reveals the promoting effect, transmission mechanisms, and moderating role of green credit policy on corporate green technological innovation.

First, this study employs a parallel trends test to verify that, prior to policy implementation, the treatment group (heavily polluting firms) and the control group (non–heavily polluting firms) exhibit similar trends in green innovation activities. The results indicate that before the policy implementation ($t < 2012$), the estimated coefficients are close to zero and their 95% confidence intervals include zero, suggesting no significant difference in green innovation levels between the treatment and control groups. This finding is consistent with the parallel trends assumption.

Second, using a difference-in-differences approach, this chapter examines the overall impact of green credit policy on firms' green technological innovation. The results show that green credit policy significantly increases both the quantity and quality of green technological innovation among listed firms, although its effect on improving innovation quality is relatively weaker.

Third, to examine the robustness of the empirical results and to eliminate potential confounding factors, this study conducts a series of robustness checks, including the PSM-DID approach, placebo tests, and a reduced time-window analysis. These tests effectively rule out alternative explanations and confirm the robustness of the empirical findings.

Fourth, a mediation effect model is employed to analyze the channels through which green credit policy influences firms' green technological innovation, focusing on three pathways: R&D expenditure, financing constraints, and the quality of corporate environmental information disclosure. The results indicate that all three mediating variables play significant roles in transmitting the effect of green credit policy on green technological innovation, with environmental information disclosure quality exhibiting the strongest mediating effect.

Fifth, a moderating effect model is used to examine the moderating roles of executives' financial backgrounds and institutional investor ownership in the relationship between green credit policy and corporate green technological innovation. The results show that both moderating variables exert positive moderating effects on this relationship. Among them, the moderating effect of institutional ownership is the most pronounced, highlighting the critical role of institutional investors in promoting corporate green technological innovation.

Finally, the heterogeneous impact of green credit policies on corporate green technology innovation was analyzed. The results show that the impact of green credit policies on corporate green technology innovation is heterogeneous, particularly in promoting green technology innovation among state-owned enterprises, large enterprises, manufacturing enterprises, and capital-intensive enterprises.

Through a comprehensive analysis of the effects of green credit policy on corporate green technological innovation, this chapter provides important insights for firms in formulating green innovation strategies and lays a solid theoretical and empirical foundation for achieving the goals of a low-carbon economy and sustainable development.

CONCLUSIONS

China is the world's largest carbon emitter, and enterprises are the main source of these emissions. Green technology innovation is crucial to achieving emission reduction goals. The purpose of this research is to analyze the impact of green credit policy on green technology innovation in enterprises. Therefore, this text uses the 2012 edition of the Green Credit Policy as a natural experiment, selected from 2006 to 2024. In order to study samples, under the general framework of sustainable development theory, using the difference-in-differences model to investigate the impact of green credit policy implementation on green technology innovation activities of listed companies. The baseline regression model, the mediation effect model, and the moderation effect model are empirically tested. Finally, this paper conducts heterogeneity analysis from the three dimensions of enterprise size, property rights, and industry attributes to further reveal the differential characteristics of green credit policies affecting enterprises' green technology innovation. The main conclusions of this paper are as follows:

First, existing research largely focuses on whether green credit promotes corporate innovation, but there is relatively little discussion on the quality of innovation. The innovation of this study lies in distinguishing between the "quantity" and "quality" of green technology innovation. The baseline regression results show that green credit policies significantly promote corporate green technology innovation, but their impact is mainly reflected in the increase in the number of green patents. Specifically, the promotion effect of green credit policies on the total number of green patents is 0.1664, and on green utility model patents it is 0.1765, both significantly higher than their promotion effect on green invention patents (0.0545). This indicates that green credit policies primarily drive an increase in the quantity of green technology innovation, while their effect on improving the quality of innovation is relatively limited. Therefore, under the background of green credit policy implementation, heavily polluting enterprises tend to prioritize quantity over quality in their innovation activities.

Second, although existing literature has explored the mechanisms of green credit from the perspectives of financing constraints and R&D investment, this study, through mechanism decomposition, finds that the mediating effect of the quality of environmental information disclosure accounts for as high as 36.14%, making it the most explanatory mechanism among the three pathways. This discovery is of great innovative significance: it not only verifies the role of traditional channels (financing, R&D), but also, for the first time, emphasizes the key role of signaling mechanisms (environmental information disclosure) in the current institutional context of China.

Third, this study innovatively introduces moderating variables at the corporate governance level. While the financial background of senior executives was confirmed to have a positive moderating effect, a more important finding is that the moderating effect coefficient of institutional investor shareholding ratio (0.5462) far exceeds that of senior executive financial background (0.1165). This result transcends the limitations of previous studies that only focused on internal corporate characteristics, revealing the positive governance role of external major shareholders in corporate green transformation. The conclusion indicates that institutional investors are not only financial investors, but also important supervisory forces and "catalysts" for promoting high-quality green innovation in enterprises, enriching empirical research in the intersection of corporate governance and green finance.

Fourth, the impact of green credit policies on corporate green technology innovation exhibits heterogeneity. Existing heterogeneity studies mostly focus on ownership heterogeneity and firm size heterogeneity. This paper further incorporates industry heterogeneity (manufacturing versus non-manufacturing firms) and capital intensity heterogeneity. The heterogeneity analysis results show that the promoting effect of green credit policies is more significant in state-owned enterprises, large enterprises, manufacturing enterprises, and capital-intensive enterprises, revealing the important influence of enterprise ownership attributes, scale characteristics, and industry attributes on policy transmission efficiency.

Fifth, the control variable analysis shows that firm size and profitability are important factors promoting green technology innovation, while growth pressure, excessive equity concentration, and firm maturity in some cases may constrain green innovation. These results not only indicate that corporate green technology innovation is influenced by external policies, but also by the combined effects of internal factors such as resource endowment, governance structure, and operational characteristics.

Research Contributions：

(1) Theoretical contributions

① This paper deepens the theoretical analytical framework for the impact of green credit policies on corporate green technology innovation. Using sustainable development theory as the overall framework, supplemented primarily by Porter's hypothesis, and incorporating environmental risk theory, resource-based view theory, financing constraint theory, stakeholder theory, upper echelon theory, and innovation diffusion theory, this paper constructs a comprehensive theoretical analytical framework for the impact of green credit policies on corporate green technology innovation. Unlike existing studies that often explain policy effects from a single theoretical perspective, this paper not only reveals the institutional logic of green credit policies serving sustainable development at the macro level, but also systematically elucidates its mechanism of action from multiple levels, including corporate resource allocation, financing conditions, external governance, and managerial characteristics.

② This paper provides a transferable analytical paradigm for extending this theoretical framework to research on other green policies. The theoretical framework constructed in this paper is not only applicable to explaining the impact of green credit policies on corporate green technology innovation, but can also be extended to analyze the mechanisms of action of other green policies. For example, in research on carbon emissions trading policies, sustainable development theory and Porter's hypothesis can still be used to explain the overall logic of the transformation of environmental regulatory pressure into innovation incentives, while the resource-based view theory can be used to analyze how companies can improve their low-carbon technology capabilities by increasing investment in green R&D. Therefore, this paper provides transferable theoretical tools and analytical approaches for research on the impact of other green policies on corporate green innovation.

(2) Practical Contributions

First, this study helps clarify the important role of green credit policies in promoting sustainable development. Empirical results show that green credit policies significantly promote green technology innovation among enterprises, driving them to shift from passive emission reduction to proactive innovation and green transformation. This not only demonstrates the important function of green credit in promoting industrial upgrading and green development, but also provides empirical evidence from Chinese listed companies for achieving the "industry, innovation, and infrastructure" and "climate action" aspects of the Sustainable Development Goals. Simultaneously, this paper expands on carbon market-related research from a green credit perspective, demonstrating that green credit policies can enhance enterprises' low-carbon transformation capabilities by promoting green technology innovation, thereby providing technical support for the carbon market to achieve long-term emission reduction targets and providing empirical evidence for the synergistic advancement of the carbon market and green credit policies.

Second, this study provides empirical evidence for the government to optimize and precisely implement green credit policies. The study found that green credit policies significantly improved the quantity and quality of green technology innovation among listed companies, but their effect on promoting innovation quality was relatively weak. This indicates that while current policies have achieved certain results, there is still room for improvement in guiding high-quality green innovation. Therefore, the government should further improve the green credit policy system, refine support standards, and enhance the pertinence and effectiveness of policy implementation.

Secondly, it provides a feasible path for enterprises' green transformation and innovation strategies. Mechanism testing shows that green credit policies mainly promote green technology innovation by improving the level of environmental information disclosure. Therefore, enterprises should improve the quality of environmental information disclosure, enhance their financing capabilities and market trust, and thus improve their green transformation capabilities and green innovation performance.

Finally, it provides practical reference for the implementation of green credit policies in other countries. For example, it offers important policy insights for resource-based developing countries like Mongolia, which face the dual pressures of economic transformation and environmental protection. Mongolia's economy is highly dependent on resource-based industries such as mining and livestock, and it faces severe ecological challenges such as grassland degradation and water scarcity. For Mongolia, establishing a green credit framework suited to its national conditions, through the proactive design and guidance of green credit policies, can internalize environmental costs, effectively incentivize the green upgrading of traditional industries, and cultivate emerging environmental protection industries.

The lessons learned from China's green credit development practice lie not in isolated policies, but in the interconnected institutional system encompassing standard setting, information disclosure, incentives and constraints, and financial product innovation. Based on this logic, the localization of Chinese experience in Mongolia can be promoted in the following three aspects:

First, establish a differentiated green credit allocation mechanism based on industry and sector. Mongolia's industrial structure differs significantly from China's. Green credit cannot simply replicate China's broad-based, industry-wide approach. Instead, it should prioritize sectors facing the greatest pressure for green transformation, possessing the strongest emission reduction potential, and exhibiting the most pressing realities, such as mining, energy, energy-efficient buildings, and climate-resilient agriculture. The World Bank points out that Mongolia's economy is heavily reliant on the extractive industry, which accounts for approximately one-quarter of its GDP; in 2023, coal mining accounted for about 12% of GDP and 58% of exports. Furthermore, the Central Bank of Mongolia's climate scenario analysis has incorporated physical risks such as drought, floods, and other natural disasters into its financial risk assessment. Given this reality, the best approach to localizing the Chinese experience in Mongolia is not to apply the same effort across the board, but rather to implement differentiated credit standards, interest rate pricing, and environmental access requirements for high-emission, high-risk industries. Green credit should be primarily directed towards green transformation of the mining industry, energy-efficient building renovations, clean heating, water-saving projects, and disaster-resistant agriculture. This approach is more aligned with Mongolia's industrial structure and is more likely to yield tangible policy results.

Second, establish a green financing support mechanism based on "policy guidance + risk sharing," focusing on alleviating financing constraints for SMEs. Mongolia's financial system is highly dependent on banks, with the banking sector accounting for approximately 91% of total assets. Commercial bank loans remain the primary source of financing for enterprises, especially SMEs. However, the World Bank also points out that local SMEs generally face insufficient collateral and credit constraints. Given this, when implementing China's green credit policy in Mongolia, best practices should not merely focus on "requiring banks to issue more green loans," but should further establish supporting mechanisms such as green refinancing, interest subsidies, guarantees, risk compensation, and wholesale financing. Mongolia's existing Mongolia Green Finance Corporation (MGFC) provides a good institutional foundation: its role is to provide wholesale financing through local partner financial institutions, focusing on supporting energy-saving renovations, green housing, and energy efficiency improvement projects. Therefore, Mongolia can learn from China's approach of policy-based finance and fiscal coordination, building upon existing mechanisms such as the MGFC and credit guarantee funds to form a green credit system based on "central bank guidance—development funds leverage—commercial bank lending—risk sharing by guarantee institutions," especially prioritizing support for SMEs lacking collateral but with green transformation needs.

Third, improve the institutional infrastructure for "green classification—environmental information disclosure—performance evaluation." A crucial prerequisite for the effective functioning of green credit in China is the gradual improvement of classification standards, information disclosure, and regulatory assessment. Mongolia already possesses a certain foundation, including the Sustainable Finance Roadmap, Green Finance Taxonomy, SDG Finance Taxonomy, Climate-Related Disclosure Guideline, as well as green loan statistics released in 2020 and green bond regulatory rules introduced in 2021. The Mongolian securities market also has ESG disclosure guidelines. The next best practice is not to start from scratch, but to further "use, tighten, and connect" these systems: on the one hand, requiring banks to embed green classification standards into credit approval, post-loan monitoring, and risk pricing; on the other hand, promoting listed companies and key borrowers to improve the quality of environmental information disclosure, reducing information asymmetry between banks and enterprises; and simultaneously establishing an evaluation mechanism for the actual effectiveness of green loans, looking not only at "how much was loaned," but also at emission reduction effects, energy efficiency improvements, pollution control, and green patent output. Only in this way can green credit truly be transformed from a "policy slogan" into a "recognizable, assessable, and replicable" best practice.

Suggestions for Future Research. Future research could further explore the impact of green credit policies on different types of enterprises, especially non-listed companies. Furthermore, it could investigate how green credit policies can be combined with other green finance policies (such as green bonds and green funds) to better promote green technology innovation among enterprises. Finally, research could explore the impact of different policy combinations on enterprise innovation, providing more empirical evidence for policymaking.

RECOMMENDATIONS

The issuance of the Green Credit Guidelines marks a further maturation of China's green credit policy framework. However, compared with developed countries, the development of green credit in China remains uneven. To ensure the sustained and effective implementation of green credit policies and to promote long-term economic and environmental development, this study proposes the following policy recommendations from the perspectives of the government, financial institutions, and enterprises, based on the preceding research findings.

(1) Policy Level

First, the government should continue to optimize the institutional framework of green credit and promote the shift of policy from "quantity-oriented incentives" to "quality-oriented guidance." Given that green credit policies currently have a significantly stronger effect on promoting the quantity of green patents than on promoting high-quality innovations such as green invention patents, the government should place greater emphasis on innovation quality orientation in policy design, refine the support standards for green invention patents, key core green technologies, and long-term R&D projects, and avoid enterprises exhibiting a short-sighted tendency of "emphasizing quantity over quality" under policy incentives. For example, the term of green credit could be adjusted according to the term of green patents, and additional subsidies, tax breaks, or lower-interest-rate credit support could be provided for the application and R&D of green invention patents to encourage enterprises to increase investment in high-tech green innovation and balance the development of green invention patents and green utility model patents.

Secondly, improve environmental information disclosure standards. Research shows that environmental information disclosure is the core transmission mechanism for green credit policies to exert their innovative incentive effect. Therefore, the government should further improve environmental information disclosure rules, unify disclosure standards, strengthen third-party auditing and regulatory constraints, and improve the authenticity, completeness, and comparability of corporate environmental information, providing a reliable basis for financial institutions to conduct green credit identification and risk assessment.

Finally, enhance the differentiated and precise implementation of green credit policies. Since green credit policies have a more significant promoting effect on state-owned enterprises, large enterprises, manufacturing enterprises, and capital-intensive enterprises, while their effect on other types of enterprises is relatively limited, the government should improve green guarantee, interest subsidy, risk compensation, and credit enhancement mechanisms to address the financing constraints faced by SMEs, private enterprises, and non-manufacturing enterprises, thereby enhancing the inclusiveness and coverage of green credit policies.

(2) Commercial Bank Level

Commercial banks should proactively respond to the call of green credit policies and maximize their positive guiding effect by adjusting their credit structure.

First, construct a credit assessment model with both quantity and quality. When approving green loans, commercial banks should not only consider whether a company has patent applications as a condition for lending. They should introduce professional assessment teams or third-party assessment agencies to focus on the technological content of the patents (whether they are invention patents), their commercialization prospects, and expected environmental benefits. Through precise allocation of credit funds, companies can be compelled to improve the quality of their innovation.

Second, develop green financial products linked to R&D investment. Given the characteristics of green technology innovation—large investment, long cycles, and high uncertainty—commercial banks can explore linking indicators such as the intensity of green R&D investment and R&D growth rate with loan amounts, interest rate discounts, and repayment periods. This will enable the launch of R&D-oriented green credit products, enhancing financial support for companies' long-term green R&D activities and alleviating funding constraints in the green innovation process.

Finally, strengthen collaboration with institutional investors. When providing green loans to listed companies, commercial banks can offer "introducing or increasing institutional investor shareholding" as a bonus or value-added service. At the same time, banks can establish information-sharing mechanisms with institutional investors such as funds and insurance companies to jointly assess the green value of enterprises, forming a "credit support

+ equity investment" investment-loan linkage model to jointly supervise and promote the green transformation of enterprises.

(3) Enterprise Level

In their pursuit of sustainable development, enterprises should strengthen green governance mechanisms, enhance their environmental awareness, and implement comprehensive green strategic planning to promote the harmonious coexistence of ecological and economic benefits.

First, enterprises should shift from a focus on quantity to a focus on quality, optimizing their green innovation strategic layout. With the support of green credit policies, enterprises should not only pursue an increase in the number of green patents but also increase investment in green invention patents, key green technologies, and long-term R&D projects to improve the quality of green technology innovation and core competitiveness.

Second, environmental information disclosure is a key pathway for green credit policies to take effect. Enterprises should enhance their awareness of environmental information disclosure, standardize disclosure content, and improve transparency and credibility to enhance financial institutions' trust, improve financing availability, and secure more external resource support for green innovation. For example, proactively disclosing the number of green patents and changes in carbon emission intensity can enhance the trust of banks and investors.

Finally, enterprises should improve their governance structure and enhance the financial literacy of management. Research shows that the financial background of senior executives and the proportion of shares held by institutional investors both contribute to strengthening the innovation incentive effect of green credit policies. Therefore, companies should prioritize attracting management talent with financial literacy and a green development mindset, while also optimizing their corporate governance structure and attracting long-term institutional investors to improve the efficiency of converting green credit policy dividends.

APPENDICES

APPENDIX 1：Shenwan China A-Share Listed Companies Industry Classification (2021 Edition) includes 31 primary industries

NO.	Level 1 code	Industry	NO.	Level 1 code	Industry
1	110000	Agriculture, forestry, animal husbandry and fishery	17	480000	Bank
2	220000	Basic Chemicals	18	490000	Non-bank financial institutions
3	220000	steel	19	510000	Comprehensive
4	240000	non-ferrous metals	20	610000	Building materials
5	270000	electronic	21	620000	Architectural Decoration
6	280000	car	22	630000	Power equipment
7	330000	Home appliances	23	640000	Mechanical equipment
8	340000	Food and Beverage	24	650000	Defnse and military industry
9	350000	Textiles and Apparel	25	710000	Computer
10	360000	Light Industry Manufacturing	26	720000	Media
11	370000	Pharmaceuticals and Biotechnology	27	730000	Communication
12	410000	public utilities	28	740000	Coal
13	420000	Transportation	29	750000	Oil and petrochemical
14	430000	real estate	30	760000	Environmental friendly
15	450000	Commerce and Retail	31	770000	Beauty Care
16	460000	Social services			

APPENDIX 2：China's "Green Credit Supported Project Catalog"

Primary Classification	Examples of core content and directions
1. Energy conservation and carbon reduction industry	Focusing on energy-saving technologies and retrofits in industries, buildings, and transportation.
2. Resource recycling industry	Support the recycling of industrial solid waste, agricultural and forestry waste, and waste materials (such as decommissioned photovoltaic modules).
3.Environmental protection industry	It covers air, water, and soil pollution prevention and control, as well as ecological monitoring.
4. Green upgrade of infrastructure	It refers to the green construction and renovation of infrastructure such as transportation, buildings, and municipal facilities.
5.Ecological protection and restoration projects	It covers ecosystem protection, restoration, and sustainable operation.
6. Green and low-carbon energy transition	Support clean energy systems such as solar, wind, hydrogen, smart grids, and new energy storage.

APPENDIX 3： Two main channels for China to extend green credit to heavily polluting enterprises

Channels	Core Logic	Key prerequisites and requirements
1. Used for pollution control and energy-saving renovation	Support the green upgrading of existing production lines to achieve energy conservation and emission reduction.	The project itself must be a purely environmental protection project, such as end-of-pipe treatment or energy-saving technological upgrades, and the technology must be advanced and the benefits quantifiable.
2. Used for transformation and development of new businesses	Support enterprises in transforming towards green and low-carbon industries and opening up new avenues.	New businesses must belong to green industries encouraged by the state and must be clearly isolated from existing heavily polluting businesses to mitigate risks.

APPENDIX 4：Heavily pollutingg industries

The Comprehensive Environmental Protection Directory released by China's Ministry of Ecology and Environment has officially defined "high-pollution, high-environmental-risk" industries (i.e., "heavily polluting" industries), which mainly cover the following areas.

Number	**Industry categories**	**Typical production activities/representative products**	**Main environmental load characteristics**
1	Thermal power	Coal-fired and gas-fired power generation	It emits large amounts of sulfur dioxide, nitrogen oxides, and soot, making it one of the major sources of air pollution.
2	Steel	Ironmaking, steelmaking, steel rolling	It has high energy consumption and high emissions, generating a large amount of waste gas, dust and solid waste.
3	Cement	Cement clinker production	It emits large amounts of dust and nitrogen oxides, and the production process is energy-intensive.
4	Electrolytic aluminum	Alumina electrolysis	It consumes a lot of electricity and produces waste gases such as fluorides and asphalt fumes during the production process.
5	Coal	Coal mining and washing	It damages the ecosystem, produces mine water, coal gangue and gas, and can easily cause water pollution and spontaneous combustion.
6	Metallurgy	Ferroalloys, coking, etc.	It consumes a lot of energy and generates a variety of toxic and harmful waste gases and wastewater during the production process.
7	Chemical Industry	Basic chemical raw materials, fertilizers, and pesticide manufacturing	The raw materials and products are mostly toxic and easily generate wastewater, waste gas and hazardous waste with complex composition.
8	Petrochemical	Crude oil processing and ethylene production	It emits volatile organic compounds, poses a high risk of fire and explosion, and the wastewater contains oil and recalcitrant organic matter.
9	Building materials	Architectural ceramics and flat glass manufacturing	It consumes a lot of energy and produces industrial dust, sulfur dioxide and nitrogen oxides.
10	Papermaking	Pulping and papermaking (especially non-wood pulp)	It produces high-concentration organic wastewater (black liquor), consumes a large amount of water, and is a major traditional water polluter.
11	Brewing	Alcohol, spirits, and beer manufacturing	It generates a large amount of high-concentration organic wastewater (brewing waste liquid) with extremely high COD concentration.
12	Pharmaceuticals	Chemical pharmaceutical raw material manufacturing	The production process is complex and generates wastewater that is highly concentrated, difficult to degrade, and biologically toxic.
13	Fermentation	Amino acids (monosodium glutamate), organic acids, etc.	Similar to brewing, it produces high-concentration organic wastewater with a high pollution load.
14	Textiles	Printing and dyeing, finishing	It generates a large amount of wastewater containing dyes, auxiliaries, etc., with high color intensity and difficult to treat.
15	Leather	Fur tanning	The use of large quantities of chemical materials generates high-concentration organic wastewater containing heavy metals such as chromium.
16	Mining	Mining and beneficiation of various metal/non-metal ores	The ecological damage is severe, resulting in tailings, acidic mine wastewater, and heavy metal pollution.

APPENDIX 5：Key environmental benefit indicators of China's "Special Statistical System for Green Loans"

Indicator Categories	**Key Indicators**
1. Energy-saving efficiency indicators	Standard coal savings
2. Emission reduction benefit indicators	$CO2$ emission reduction equivalent Chemical oxygen demand (COD) emission reduction Ammonia nitrogen (NH_3-N) emission reduction Sulfur dioxide (SO_2) emission reduction Nitrogen oxide (NOx) emission reduction Emission reduction of fine particulate matter (PM2.5) and other volatile organic compounds
3. Other synergistic benefit indicators	Water-saving benefits Material saving benefits Other aspects include noise reduction and the comprehensive utilization of solid waste.

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