Study on the Impact of Supply Chain Finance on Corporate Green Innovation

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ABSTRACT

This study uses the data of China A-share listed companies from 2010 to 2023. It uses text analysis to construct enterprise-level supply chain financial indicators. It systematically studies the influence of supply chain financing on enterprise green innovation, its potential mechanism and its heterogeneous performance. The results show that: firstly, supply chain financing has significantly promoted the green innovation of enterprises. Through several tests, this conclusion is still strong, indicating that supply chain financing has effectively solved the restrictive financing problem of green innovation. Secondly, the catalytic effect shows significant heterogeneity, especially in state-owned enterprises (SOEs) and companies with high equity concentration. State-owned enterprises use their core position in the supply chain to make more effective use of supply chain financing, while equity-centered enterprises rely on effective decision-making mechanisms to turn external financing into green innovation results. Finally, reducing the difficulty of financing is the main mechanism for supply chain financing to support green innovation. This proves the transfer chain: "Supply chain financing is also a financing constraint, and further strengthen green innovation. The research results provide a basis for the green innovation and development of enterprises. We put forward policy suggestions from the government, enterprises and financial institutions to promote the common development of supply chain finance and green finance, and implement different support policies to improve the effectiveness of financing difficulties. These suggestions are of great significance in theory and practice.

Keywords: green innovation; supply chain finance; financing constraints

1. INTRODUCTION

Under the background of the intensification of global climate change and the promotion of the goal of "double carbon", green innovation has become an important way for enterprises to achieve sustainable development. However, green innovation needs a lot of money, takes a long time to make money, and has high technical risks. It is often difficult for companies to find enough money (Hall and Lerner,2010) [6], which is a big problem to prevent them from becoming greener. Recent research also shows that the lack of funds is the most direct obstacle to green investment of enterprises. Because green projects are risky and time-consuming, it is difficult to obtain ordinary bank loans (Ji,2024; Yang, 2024) [18] [34]. At the same time, supply chain financing, which is a new way to make money by using real transactions between enterprises in the chain, has attracted great attention of researchers and enterprises in recent years. Different from traditional bank credit, traditional bank credit depends on the financial strength of the entity, and supply chain financing is supported by assets such as customer accounts, inventories and prepayments. By transferring credit to resettlement enterprises to reduce information asymmetry, it can effectively provide funds for small and medium-sized enterprises with long supply chains (Yang and Xu,2024; Fan and Peng, 2025) [34]. Recent research shows that in green supply chain, supply chain financing can provide credit support for chain enterprises by using the strength of core enterprises and the overall stability of the chain. The credit decision-making of financial institutions is changing: they no longer only pay attention to the risk of a single company, but evaluate the transaction quality of the whole supply chain and the ability of core companies to fulfill their commitments (Fan and Peng,2025). Further research confirms that the green credit policy can guide enterprises to transform to low-carbon and green technologies by optimizing the allocation of credit resources. These policies encourage financial institutions to provide funds for companies with strong environmental responsibilities, while restricting financing for highly polluting enterprises (Sun and Shao,2025) [30].

The Central Committee of the Communist Party of China (CCCPC) and the State Council attach great importance to the coordinated development of financial supply chain. In 2024, the People's Bank of China and other departments jointly issued the "Guiding Opinions on Further Strengthening Financial Support for Green Economy Low-carbon development",

clearly put forward the development of supply chain financing model, combined with "data credit+physical mortgage" in a collaborative way. In 2025, the People's Bank of China and the State Financial Supervision Administration and other departments officially issued the Notice on Standardizing Supply Chain Finance and Guiding Supply Chain Information Service Institutions to Better Serve SME Financing. The note emphasizes the importance of using "data credit" and "physical collateral" to help small and medium-sized enterprises obtain loans, which use collateral such as orders, inventory and warehouse receipts. She also encouraged commercial banks to try the "supply chain core model". This means that instead of focusing only on whether a company is stable, it is better to pay attention to its actual performance in the transaction. These new rules raise a very important question: Can supply chain financing help enterprises achieve green innovation?

The existing research is very important to our research. In the field of green innovation, researchers have studied the factors that drive it, such as environmental rules, state aid, and whether leaders consider the environment (Qi et al., 2018; Li et al., 2020) [19] [27]. However, the problem of funds and the restriction of financing are still a major obstacle. In the field of supply chain finance, many studies show that it can help small and medium-sized enterprises make more money (Song et al., 2024; Gelsomino et al., 2016) [11] [29]. But few studies directly link these two things or explain how it works. Recently, some researchers began to study the green effect of supply chain finance (Wang et al., 2023; Zhang et al., 2024) [37], but this is mainly theory. It still lacks a large number of data tests and empirical tests based on large sample panel data.

Therefore, this study uses the data of China A-share listed companies from 2010 to 2023 to construct the text indicators of supply chain financing companies. It empirically examines the impact of supply chain financing on enterprise green innovation, its heterogeneity and potential mechanism. The basic regression shows that after controlling the fixed effect of company and year, the supply chain financing (SCF) is significantly positive at the level of 5%, indicating that SCF has greatly promoted the green innovation of enterprises. On this basis, this study investigates the influence of SCF on green innovation and confirms the existence of this promoting effect. This phenomenon is more obvious in state-owned enterprises and enterprises with high equity concentration. The mechanism test shows that reducing financing constraints is the key channel for supply chain financing to promote green innovation. This greatly reduced the company's SA index, and the subsequent relaxation of financing restrictions further improved the level of green innovation. This forms a conduction chain, "supply chain financing lightens financing constraints, thus stimulating green innovation". The research results provide theoretical basis and empirical support for improving green financial policies, optimizing supply chain financial design and guiding enterprises' green transformation.

1.1 A Study on the Influencing Factors of Green Innovation

Measuring green innovation is the basis of this study. The existing research mainly adopts two methods: first, based on the objective indicators of patent data, the World Intellectual Property Organization (WIPO) green patent list is used for identification (Qi et al., 2018; Guo, et al, 2025) [14]. This method is widely used because its data is objective and easy to compare. Among these patents, the technical content of invention patents is higher than that of utility model patents, which is considered to be more representative of real green innovation (Li Hezheng, 2016) [21]. The second method involves subjective evaluation based on questionnaires (Alhaddad et al., 2023) [4], but this method is greatly influenced by the opinions of respondents, which is why the main research mainly relies on patent data.

At the external environment level, the strength of environmental laws and regulations is recognized as an important force (Jaffe et al., 2005) [2]. Based on the study of green credit policy, (Guo et al. 2025) [15] found that the tolerance of environmental laws and regulations for short-term failure eased green innovation-when the policy lacked tolerance for short-term failure, companies tended to increase non-innovative environmental investment, thus using resources for green innovation. Government environmental subsidies (Liu et al., 2022) [22] and market competition pressure (Porter and van der Linde,1995) [26] also played an important role. At the organizational level, company characteristics, such as scale, profitability and governance structure, affect green innovation decisions (Zhou et al., 2017) [39]. At the individual level, the implementation of environmental awareness (Li et al., 2020) [20] and management incentives (Liu et al., 2024) [27] also show significant impact.

It is important to know that, for whatever reason, green innovation needs a lot of money. Many studies show that the shortage of funds is a big problem for companies wishing to carry out green innovation (Hall and Lerner,2010) [6] [17]; Savignac, 2008. Green projects are often risky and time-consuming, so banks do not always want to borrow money. Therefore, many companies stop or postpone the research on green technology without sufficient funds.

1.2 Research on the Economic Consequences of Supply Chain Finance

Supply chain financial measurement also follows two paradigms: First, text-based analysis uses word frequency statistics. By capturing and calculating the key words in the annual reports of listed companies, it constructs the enterprise-level indicators of supply chain financing activities (Yang and Xu,2024) [35]. This method draws lessons from the text analysis paradigm of Loughran and McDonald (2011) [23], and well reflects the degree of the company's participation in supply chain financing. The second method is to construct a multidimensional composite evaluation index by using methods such as "losing weight" (Wang et al., 2025) [36].

The role of supply chain financing in helping enterprises get more funds is well known. (Berger and Udell 2006) [3] said that when a bank knows a company very well, even if you don't know everything about it, it will help it complete a big project. (Song Hua et al. 2024) [30] studied the small and medium-sized enterprises in China and found that supply chain financing helped them shorten the debt period and make them work better. (Caniato et al. 2019) [11] also confirmed that this is of great help to private companies and companies that invent new things. (Yang and Xu 2024) [35] look for the green sector. They found that supply chain finance helps companies to carry out green technology innovation by giving them more money, but in some cases the effect is better. (Fan and Peng 2025) [8] have shown that supply chain financing can help enterprises become greener by giving them more credit, and when the company has a good reputation, it will help more.

With the deepening of research, researchers pay more and more attention to the spillover effect of supply chain financing. (Cui 2025) [33] shows through empirical evidence that the level of supply chain financing has a significant positive impact on the performance of green innovation, and green management innovation plays an intermediary role. In the field of sustainable supply chain financing, (Muneeb et al. 2025) [24] established a multi-stakeholder ecosystem framework for sustainable supply chain financing and explored all its environmental, social and governance benefits.

In short, the existing research has formed two different directions: first, in the field of green innovation, researchers have examined its driving factors from the perspectives of environmental regulations, political subsidies and leadership awareness, and identified financial constraints as the main obstacle. Secondly, in the field of supply chain financing, many studies have confirmed its role in reducing financing constraints, and began to pay attention to its green effect.

However, the existing research still needs to be improved. First of all, although research shows that supply chain financing helps to obtain financing, and green innovation is often difficult to obtain funds, there is not enough research to directly link the two and verify this link well: "Supply chain financing reduces the difficulty of financing, thus enhancing green innovation. Secondly, the current research is not enough to study how the differences between companies (such as who owns the company or how to manage the company) can change this relationship. Third, we need to use a large number of data (large data sets) of China companies listed by A-shares to conduct more tests. This paper aims to make up for these defects. It uses the data of A-shares listed companies in China from 2010 to 2023 to study: the impact of supply chain financing on green innovation, the role of financing difficulties as an intermediate step, and how the differences between companies change all this.

The structure of this paper is as follows: the second section introduces the literature review and theoretical assumptions; The third part explains the research design, including data source, variable measurement and model specification; The fourth part analyzes the empirical results; Section V examines heterogeneity and testing mechanism; And the end of section VI and policy implications.

2. THEORETICAL HYPOTHESIS

This paper aims to explore the impact of supply chain finance on corporate green innovation and its underlying mechanisms. Green innovation faces severe financing constraints and market failures due to its "dual externalities" (environmental positive externalities and knowledge spillovers) and characteristics of high risk and long cycles (Jaffe et al., 2005; Acemoglu et al., 2012) [1] [2]. As a financing mode from real transactions in the industrial chain, supply chain financing can affect the green innovation decision of enterprises by helping to solve financing problems. Firstly, this part puts forward a big hypothesis: supply chain financing is helpful to green innovation of enterprises, and explains how it works. Then, from the theoretical analysis, it puts forward the hypothesis about the intermediary effect of financing constraints and the intermediary effect of corporate heterogeneity.

Existing research shows that green innovation needs a lot of stable funds to exist, but the lack of funds is the biggest problem faced by companies wishing to carry out green innovation (Hall and Lerner,2010) [6]. Supply chain financing is a

new way to make money, based on real transactions in the production chain. It can help enterprises reduce capital problems in many ways, thus providing resources for green innovation:

Improve the accessibility of financing: For many small and medium-sized enterprises without sufficient guarantee or credit history, the uncertainty of green technology makes it more difficult to obtain credit. Supply chain financing uses the good reputation of large companies and the overall stability of the supply chain to help supply chain companies obtain credit (Wuttke et al., 2013) [9]. Financial institutions are no longer only concerned about the risks of one company. Instead, they pay attention to the transaction quality of the whole supply chain and the ability of large enterprises (core enterprises) to fulfill their commitments. This change in risk assessment enables companies that were previously unable to obtain credit to obtain financial support (Pfohl and Gomm,2009) [25]. Easier access to funds means that companies have more funds for research and development of green technologies.

Reduce financing cost and maturity lag: Supply chain financing can shorten the capital cycle by effectively mobilizing recurrent assets such as accounts receivable and inventory, thus reducing the demand for expensive short-term financing (Berger and Udell,2006) [3]. At the same time, its structural design is more in line with the long-term financing needs of green R&D projects, reducing the liquidity risk of short-term loans for long-term investment. With the decrease of financing cost and the improvement of financing term structure, companies have more resources to invest in green innovation activities, which are often long and risky.

According to the above analysis, supply chain financing provides a very important financial support for green innovation of enterprises. It achieves this goal by improving financing channels, reducing financing costs and optimizing financing clause structure. This will help to generate more green innovation. This is why this paper puts forward the H1 hypothesis.

H1: Supply chain finance can promote green innovation in enterprises.

Reducing financing constraints is the main way for supply chain financing to help green innovation. Theoretically, the role of supply chain financing in reducing these restrictions has been fully confirmed: relationship-based financing can help companies with difficult information to make long-term investments (Berger and Udell,2006) [3]. Supply chain finance reduces restrictions by shortening debt maturity and improving operational efficiency (Song Hua et al., 2024) [30]; For private and innovative companies, this effect is particularly strong (Caniato et al., 2019) [11]. This study uses the SA index to measure financial constraints (Hadlock and Pierce,2010) [16]. When the index is higher, the binding force is stronger. When supply chain financing greatly reduces the company's SA index (that is, reduces the financing restrictions), the company will have more resources. Then, it can invest in the research and development of green technology, buy environmental protection equipment and develop a green patent portfolio. Thereby increasing the output of green innovation. On this basis, the H2 hypothesis is put forward.

H2: Supply chain finance promotes corporate green innovation by alleviating financing constraints through this intermediary channel.

3. DATA SOURCES AND VARIABLE MEASUREMENT

3.1 Estimation Model

To examine the impact of supply chain finance on corporate green innovation, this paper specifies the following benchmark fixed-effects model:

$$\mathrm{GreenInnovation}_{it} = \alpha_0 + \alpha_1\,\mathrm{SCF}_{it} + \alpha_2\,\mathrm{Control}_{it} + \delta_i + \mu_t + \varepsilon_{it} \quad (1)$$

The subscripts i and t denote firm and year, respectively. The dependent variable $\mathrm{GreenInnovation}_{it}$ represents the green innovation level of firm i in year t, while the core independent variable SCF_{it} measures the firm-level development of supply chain finance. Controlit comprises a set of control variables, including firm size (size), firm age (age), return on assets (ROA), growth rate (growth), board size (Director), equity concentration (ShareholdingRatio), and proportion of independent directors (indp). δ_i represents the individual fixed effect, controlling for firm heterogeneity that does not change over time; μ_t is the year fixed effect, controlling for time trends such as macroeconomic shocks; ε_{it} denotes the random error term. All regressions are adjusted for cluster standard errors at the firm level.

3.2 Data Source

The data used in this paper primarily consists of three components:

Supply chain financial data: We use Python text analysis technology to extract keywords from the full text of annual reports of China A-share listed companies from 2010 to 2023. This is helpful to establish the frequency index of supply chain financing terms. The keyword library brings together academic works and industry practices. It includes dozens of major and related terms, such as accounts receivable financing, factory, inventory planning, supply chain financing, reverse discount and dynamic discount.

Green patent data: from CNRDS China research data service platform. These patents are identified and matched through WIPO's internationally recognized green patent list. The data includes patent application number, application date, applicant, IPC classification code and other detailed information.

Financial and governance data of listed companies: from CSMAR database, covering company profile, balance sheet, income statement, corporate governance module, etc.

According to the previous literature, the initial sample treatment is as follows: -excluding listed companies in the financial industry; -Exclude companies marked ST, ST or PT during the sampling period; -Exclude missing observations of key variables. In order to reduce the influence of extreme values, all continuous variables are subtracted from the highest and lowest values by 1%.

3.3 Variable construction

3.3.1 Dependent Variable

The dependent variable Green Innovation in this paper represents the level of corporate green innovation. In micro-innovation economics research, patent data is widely adopted as a key indicator for measuring innovation output due to its objectivity, systematic nature, strong comparability, and high correlation with corporate technological innovation activities (Griliches, 1990; Hall et al., 2005) [14] [18]. Particularly for technology-driven activities like green innovation, identification and measurement based on patent classification information have become the mainstream approach in top-tier domestic and international literature (Acemoglu et al., 2012; Qi et al., 2018) [1] [14].

Invention patents are more strictly examined by China National Intellectual Property Administration (CNIPA) than utility model patents, so they have higher technical level and are more innovative. They better demonstrate the company's real innovation, not just strategy (Li and Zheng, 2016. He et al., 2018) [21] [10]. Therefore, like the research of Qi et al. (2018) and Wang and Zhao (2019) [14] [32], this study selects the number of green invention patents applied by the company within one year to measure its green innovation output.

3.3.2 Core Explanatory Variable

The main explanatory variable SCF represents the development of enterprise-level supply chain financing. Accurate measurement of supply chain financing activities at the enterprise level is very important for this study. This paper uses text analysis, which is a method that is increasingly used to measure the non-financial activities of companies in recent studies. By analyzing the full text of the annual reports of listed companies, we construct the indicators of the development level of supply chain finance. The logic is that the annual report is the official text that the company management conveys its strategy and practice to external stakeholders. The frequency and depth of supply chain financing mentioned in these reports reflect the actual commitment and strategic importance of the company to these activities (Loughran and McDonald,2011) [23]. In recent years, using text analysis technology to measure the behavior characteristics of enterprises that are difficult to observe (such as digital transformation and the use of big data) has become a frontier method of economic research (Hoberg and Phillips,2016; Wu et al., 2021; Zhang et al., 2021) [13] [34] [40].

Using this established model, this study constructs a dictionary, which includes important terms, such as "accounts receivable financing", "inventory planning", "factory" and "supply chain financing". Then, we check and calculate the number of times these words appear in the annual reports of all A-share companies from 2010 to 2023. In order to avoid the difference in report length from affecting the results, we divide the number of words by the total number of words in each report (tens of thousands). This gives the main variable SCF. The higher SCF value indicates that the company is at a higher level in the development of supply chain financing.

3.3.3 Control Variables

To control for other factors potentially influencing corporate green innovation, this study incorporates a series of control variables referenced from relevant literature in corporate innovation and corporate finance (Zhou et al., 2017; Zhang, Yeqing et al., 2021) [39] [40], a series of control variables were introduced. These specifically include: firm size (size),

represented by the natural logarithm of total assets to control for resource endowment and economies of scale; firm age (age), represented by the natural logarithm of listing duration to control for life cycle effects; profitability, represented by return on assets (ROA) to control for internal capital availability (Hall and Lerner, 2010) [6]; Growth, measured by revenue growth rate, to control for innovation pressure from growth opportunities; and corporate governance variables, including Board Size (Director), represented by the natural logarithm of the number of directors; Shareholding Concentration (Shareholding Ratio), represented by the sum of the top three shareholders' stakes; and Independent Director Proportion (indp), to control for the potential influence of governance structures on innovation decisions (Balsmeier et al., 2017) [5].

3.4 Descriptive statistics

Table 1. Descriptive statistics

Var Name	O bs	Mean	SD	Min	Median	Max
SCF1	4916	0.36	0.636	0	0	4.369
lngregrainvnum	4916	1.08	1.131	0	0.693147	4.770685
size	4916	22.42	1.579	19.26786	22.09894	27.08078
age	4916	1.84	0.741	0	1.945910	3.044523
ROA	4916	0.05	0.058	-0.31912	0.043374	0.272836
growth	4916	0.20	0.374	-0.657557	0.142816	3.247251
Director	4916	2.29	0.25	1.609438	2.302585	2.944439
Shareholding Ratio	4916	10.67	14.375	0.1091	4.216000	60.0389
Ind p	4916	0.38	0.066	0.25	0.363636	0.6

Table 1 shows the descriptive statistics of important variables. The average value of enterprise green innovation is 1.03, the standard deviation is 1.096 and the median value is 0.693. This tells us that green innovation activities among enterprises are very unequal. Our main explanatory variable, supply chain financing level (SCF), has an average value of 0.40, a standard deviation of 0.693, a minimum value of 0 and a maximum value of 4.564. This shows that there are great differences in the supply chain financial information shared by companies in their annual reports. For the control variable, the average company size is 22.08, which is similar to other studies. The average rate of return on assets (ROA) is 5%, and that of independent directors (indp) is 38%. These two values are typical characteristics of listed companies in China.

4. EMPIRICAL RESULTS ANALYSIS

4.1 Baseline regression results

Table 2 shows the basic regression results of supply chain financing (SCF) on enterprise green innovation. This study presents the results of using the stepwise fixed effect method. Column (1) contains only control variables and no fixed effect. Here, the SCF coefficient is -0.084, which is significantly negative at the level of 5%. This may indicate deviation due to unobserved omitted variables. (2) A fixed year effect is added to control common time trends, such as macroeconomic cycle and political environment. Here, the SCF coefficient becomes -0.003, which is no longer meaningful. This shows that the time trend factor has a great influence on the results. (3) further control personal fixed influence to absorb the influence of company-specific characteristics that do not change with time (for example, corporate culture, founder characteristics, long-term strategy). This constitutes the specification of the main model of this paper. Here, the SCF coefficient changes from a negative number to a positive number of 0.014, but it is still not significant. This shows that supply chain financing and green innovation show a positive correlation after controlling the influence at the enterprise level, despite the lack of statistical accuracy. Column (4) indicates the fixed effect of reference specification, control company and year; The results show that the SCF coefficient is 0.069, which is significant at the level of 5%. This means that after controlling the heterogeneity and time trend of the company, every unit (standard deviation) of a company's supply chain financing activities will lead to an increase of about 7% in its green patent application. This provides empirical support for H1 hypothesis, and proves that supply chain finance effectively promotes green innovation activities of enterprises.

For the control variable, the company size (size) coefficient in all columns is significantly positive. This shows that large companies are more able to take advantage of the green innovation advantages of supply chain financing. As we discussed in theoretical analysis, the main mechanism is to reduce financial constraints. Large companies usually have more stable cash flow, greater bargaining power and easier access to credit, which enables them to absorb and utilize the liquidity released by supply chain financing more effectively. Therefore, they can better guide these extra resources to green R&D activities with long-term risks, thus generating more green innovations. The company age coefficient is not important in the basic model. The return on assets (ROA) is significantly positive, which further supports the view that internally generated funds and improved financial conditions (key aspects of reducing financial constraints) are essential to support green innovation.

Table 2. Benchmark Regression Results

	(1)	(2)	(3)	(4)
	Green Innovation	Green Innovation	Green Innovation	Green Innovation
SCF	-0.084**	-0.003	0.014	0.069**
	(-2.08)	(-0.07)	(0.43)	(2.25)
size	0.398***	0.408***	0.138***	0.204***
	(14.82)	(15.55)	(2.87)	(3.86)
age	-0.080**	-0.065*	-0.105**	0.029
	(-2.07)	(-1.69)	(-2.15)	(0.42)
ROA	0.751*	0.877**	0.666**	0.930***
	(1.87)	(2.17)	(2.14)	(3.12)
growth	0.004	0.025	0.001	0.020
	(0.10)	(0.63)	(0.02)	(0.55)
Director	-0.012	-0.087	0.057	0.044
	(-0.12)	(-0.93)	(0.86)	(0.68)
Shareholding Ratio	-0.001	-0.001	-0.002**	-0.002*
	(-0.86)	(-0.50)	(-2.38)	(-1.96)
Ind p	1.115***	1.070***	-0.290	-0.284
	(3.14)	(3.12)	(-1.10)	(-1.10)
_cons	-8.085***	-8.085***	-1.862*	-3.715***
	(-13.34)	(-13.79)	(-1.78)	(-3.22)
Time-fixed	No	Yes	No	Yes
Individual fixed	No	No	Yes	Yes
N	4916	4916	4916	4916
Adj.R^2	0.28	0.32	0.01	0.09

Note: *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. The standard errors in parentheses are calculated at the enterprise level. (Same applies to the table below).

4.2 Robustness Test

In order to verify that the conclusion of benchmark regression is reliable, this paper has carried out several robustness tests. We focus on different aspects, such as measuring the main variables, how the model is constructed, and the selected samples.

4.2.1 Changing the measurement method of the dependent variable

Measuring the differences in green innovation methods of enterprises may change the estimation results. Our reference regression uses the natural logarithm of the number of Green Innovation as the main dependent variable. This helps us to measure the high quality of substantive green innovation. In order to see whether our conclusions will change according to the selected innovation type, this study follows the method of Zhao, (Yu et al. 2021). The dependent variable is replaced by the natural logarithm of the total number of green patents (including inventions and utility models) (greg). Although utility model patents require less innovation than patented inventions, they also show good results when companies use green technologies. The result of regression is in column (1) of Table 3. The coefficient of the main explanatory variable SCF is significantly positive at the level of 5%. This means that supply chain financing not only contributes to the high quality of green innovation (invention), but also encourages more green technology application activities. This confirms that our reference conclusion is solid.

4.2.2 Changing the measurement method of the core explanatory variable

How to measure the financial level of supply chain may affect the estimation results. SCF used in reference regression is a standardized word frequency indicator. In order to eliminate the potential measurement error caused by specific standardization methods, this study uses the total original frequency of supply chain financing words (SCF_ initial) as an alternative explanatory variable in regression. The result is shown in column (2) of Table 3, where the coefficient of SCF_ initial is 5%. This result further confirms that the positive relationship between supply chain financing and enterprise green innovation is still very important no matter what word frequency processing method is used, which enhances the credibility of the main conclusions.

4.2.3 Controlling for time-varying industry heterogeneity effects

Industry differences in green innovation foundation, technological opportunities and policy environment may change over time. If we don't consider these factors, it may lead to our calculation errors. In order to better control these factors which vary with industry and year, a fixed "industry × year" effect is added to the main model. This very rigorous approach takes into account all trends specific to the industry over time (for example, technological breakthroughs in the industry or the implementation of centralized environmental policies). The regression results (Table 3, column (3)) show that even after controlling this "industry year" effect, the SCF coefficient is still statistically significant at the level of 10%. This means that the positive impact of supply chain finance on green innovation is not caused by the impact of industry changes over time. Therefore, this strengthens the internal validity of our findings.

4.2.4 Incorporating Additional Corporate Financial and Governance Characteristics

Although benchmark regression controls many characteristics of the company, the capital structure and governance details of the company can affect the financing strategy and innovation decision at the same time. In order to reduce the potential problems of omitting variables, the debt-to-equity ratio (Lev) and the number of directors (Director #) are added to the control variables. The ratio of debt to equity shows the financial leverage and risk status of the company, and the size of the board of directors may affect the effectiveness of decision-making. The result of regression is shown in column (4) of Table 3. After adding these two variables, the coefficient of SCF keeps obviously positive at the level of 5%, and its value is basically consistent with the baseline results. This shows that the reference conclusion is insensitive to the choice of control variables.

Table 3. Robustness Tests

	(1)	(2)	(3)	(4)
	greg	Green Innovation	Green Innovation	Green Innovation
SCF	5.338*		0.063*	0.069**
	(1.66)		(1.87)	(2.24)
SCF_ initial		0.017**		
		(2.26)		

Table 3. (continued) Robustness Tests

	(1)	(2)	(3)	(4)
	greg	Green Innovation	Green Innovation	Green Innovation
size	6.146	0.203***	0.180***	0.211***
	(1.11)	(3.84)	(3.18)	(3.96)
age	13.353	0.026	0.010	0.037
	(1.42)	(0.37)	(0.12)	(0.53)
ROA	23.106**	0.937***	1.076***	0.859***
	(1.98)	(3.14)	(2.99)	(2.80)
growth	-2.369	0.022	-0.002	0.024
	(-1.45)	(0.60)	(-0.05)	(0.65)
Director	8.098	0.042	0.058	0.058
	(1.31)	(0.64)	(0.82)	(0.73)
Shareholding Ratio	0.001	-0.002**	-0.001	-0.002*
	(0.01)	(-1.98)	(-1.63)	(-1.95)
Ind p	-33.174	-0.292	-0.351	-0.280
	(-1.35)	(-1.13)	(-1.17)	(-1.09)
Director Number				-0.003
				(-0.29)
Lev				-0.117
				(-0.53)
_cons	-155.027	-3.688***	-3.813***	-3.833***
	(-1.18)	(-3.19)	(-2.86)	(-3.35)
Time-fixed	Yes	Yes	Yes	Yes
Individual fixed	Yes	Yes	Yes	Yes
N	9619	4916	3842	4916
Adj.R^2	0.01	0.09	0.08	0.09

4.3 Heterogeneity Test

Theoretical analysis shows that the influence of supply chain finance may show systematic heterogeneity. This paper examines this heterogeneity from two aspects: the nature of corporate ownership and the degree of financing constraints.

4.3.1 Heterogeneity in Firm Ownership Structure

Table 4 shows the regression results grouped by attribute type. Column (1) represents the sub-sample of state-owned enterprises (SOE=1), in which the SCF coefficient is 0.099, which is significant at the level of 10%. Column (2) shows the sub-sample of non-state-owned enterprises (SOE=0), and the SCF is 0.055, which is not important.

This result is completely contrary to the expectation of H3 hypothesis. This study found that the role of supply chain financing in promoting green innovation is actually more obvious in state-owned enterprises. One possible explanation is

that state-owned enterprises often play the role of "core enterprises" in the supply chain system of China. They have stronger ability to establish and lead the supply chain financing ecosystem, so that they can use supply chain financing tools more effectively and deeply to serve their strategic goals, including green transformation. However, non-state-owned enterprises are mainly supporting enterprises in the supply chain. Although they have urgent financing needs, they may lag behind state-owned enterprises in obtaining, negotiating and deeply applying supply chain financial products, which makes innovation promotion not fully realized. This discovery has great policy significance, indicating that when promoting supply chain finance to support innovation, we should focus on improving the participation and benefit ability of SMEs.

4.3.2 Heterogeneity in Equity ConcentrationSub heading

In this study, the samples are divided into high and low equity concentration groups according to the average values of industries and years, in order to examine the differences in the influence of supply chain financing on green innovation of corporate governance structure. The regression results, as shown in the table, reveal the significant positive effect of the high fair concentration group, while the low fair concentration group failed the significance test. This shows that the promotion of supply chain finance to green innovation is mainly visible in companies with high equity concentration, but no significant impact is observed in samples with low equity concentration.

This result can be explained from the perspective of corporate governance. First of all, greater stock concentration usually means that major shareholders have more power to supervise and make decisions. This enables them to guide leaders to use external funds (such as supply chain financing) for activities that create long-term value, such as green technology research and development and patent development. The existence of large shareholders reduces the internal cost of the organization, which prevents managers from reducing green investment because of the pressure to achieve good performance in the short term. This makes it easier for the funds released by supply chain financing to be transformed into real innovation. Secondly, centralized ownership helps to quickly gather internal and external resources, so as to quickly make decisions and invest in R&D after obtaining supply chain financing. In contrast, companies with scattered stocks may miss investment opportunities because of high coordination costs and lengthy decision-making chains, which weakens the efficiency of turning funds into innovation. In addition, major shareholders usually have greater industry expertise and better resource networks. This enables them to provide technical support or market channels and funds for green innovation projects. This further improves the efficiency of supply chain financing. Although very high stock concentration may also lead to the risk of "asset divestiture" of major shareholders, the empirical results of this paper support the dominant position of "regulatory effect". This shows that major shareholders are playing an active governance role in the green transformation.

These findings have important practical significance: when formulating green financial policies, we must pay attention to the regulatory role of the company's equity structure. For companies with decentralized ownership, measures such as improving board governance and strengthening the protection of minority shareholders can help ensure that external funds are used for green innovation. On the contrary, for companies with centralized ownership, protective measures are needed to prevent major shareholders from using their control rights to deviate from the green development goals. Future research can further explore the interactive effect of ownership characteristics (such as state ownership) and ownership concentration, so as to better understand the green governance mechanism of enterprises.

Table 4. Heterogeneity Analysis: Grouped by Enterprise Ownership Structure

	(1)	(2)	(3)	(4)
	state-owned enterprise	non-state-owned enterprise	high equity concentration	low equity concentration
SCF	0.099*	0.055	0.091**	0.040
	(1.79)	(1.47)	(2.03)	(0.92)
size	0.400***	0.090	0.144**	0.101
	(4.17)	(1.58)	(2.19)	(1.43)
age	0.079	0.147*	-0.085	0.087
	(0.51)	(1.78)	(-0.44)	(0.89)

Table 4. (continued) Heterogeneity Analysis: Grouped by Enterprise Ownership Structure

	(1) state-owned enterprise	(2) non-state-owned enterprise	(3) high equity concentration	(4) low equity concentration
ROA	1.661**	0.595*	0.938*	0.931**
	(2.41)	(1.80)	(1.82)	(2.30)
growth	-0.064	0.022	0.001	-0.013
	(-0.93)	(0.60)	(0.01)	(-0.38)
Director	0.166	-0.044	0.193**	-0.104
	(1.47)	(-0.55)	(1.97)	(-1.14)
Shareholding Ratio	-0.003**	-0.000	-0.001	-0.005
	(-2.56)	(-0.09)	(-1.56)	(-1.08)
Ind p	-0.023	-0.415	-0.546	-0.164
	(-0.05)	(-1.42)	(-1.44)	(-0.41)
cons	-8.545***	-1.145	0.000	0.000
	(-3.71)	(-0.97)	(.)	(.)
Time-fixed	Yes	Yes	Yes	Yes
Individual fixed	Yes	Yes	Yes	Yes
N	1699	3217	2979	1907
Adj.R^2	0.18	0.05	0.13	0.09

4.4 Mechanism Test: Channels for Easing Financing Constraints

This paper examines whether supply chain finance promotes green innovation by alleviating corporate financing constraints. Drawing on existing research, the SA index (taken as an absolute value) is employed as a proxy for financing constraints (Hadlock and Pierce, 2010), where a higher value indicates stronger financing constraints.

Table 5. Mechanism Analysis

	(1) SA	(2) Green Innovation
SCF	-0.006***	
	(-2.914)	
SA		-0.557*
		(-1.918)
size	-0.008	0.202***
	(-1.327)	(5.308)
age	0.068***	-0.005
	(11.092)	(-0.089)

Table 5. (continued) Mechanism Analysis

	(1)	(2)
	SA	Green Innovation
ROA	-0.021	0.782***
	(-1.583)	(3.815)
growth	0.008***	-0.012
	(4.625)	(-0.460)
Director	0.003	0.019
	(1.077)	(0.395)
Shareholding Ratio	-0.000***	-0.001
	(-4.879)	(-1.575)
Ind p	0.002	-0.398**
	(0.119)	(-2.197)
_cons	3.578***	-1.662
	(29.113)	(-1.234)
Time-fixed	Yes	Yes
Individual fixed	Yes	Yes
N	15410	9079

5. CONCLUSIONS AND POLICY IMPLICATIONS

5.1 Key Findings

This study uses text analysis to create enterprise-level supply chain financial indicators, using the data of China A-share listed companies from 2010 to 2023. It systematically studies the influence of supply chain finance on green innovation of enterprises, how it works and its various manifestations. The main conclusions are as follows:

5.1.1 Supply chain finance significantly promotes corporate green innovation

Supply chain finance helps enterprises to achieve green innovation to a great extent. Our analysis shows that supply chain finance has solved the problem of raising funds for green innovation. This result is always correct when the dependent variable (total green patent) is changed, the main variable (original word frequency) is changed, the industry-year effect is controlled, and other control variables (ROA, Director) are added. This proves that supply chain finance really helps to find funds for green innovation and is a very important financial tool to help enterprises become greener.

5.1.2 The promotional effect of supply chain finance exhibits significant heterogeneity

The promotion effect of supply chain financing shows great differences. The regression results show that the influence of supply chain financing on green innovation is the strongest among state-owned enterprises and enterprises with high concentration of shareholders. This finding shows that enterprise characteristics play an important role in the green effect of supply chain financing: state-owned enterprises make better use of supply chain financing and become greener; Companies with centralized shareholders use their rapid decision-making mechanism and supervision ability to prevent funds from being used too late, so that external funds can really be used for green innovation.

5.1.3 Alleviating financing constraints constitutes the core mechanism through which supply chain finance promotes green innovation.

Relieving financing constraints is the main mechanism for supply chain finance to help green innovation. The verification of this mechanism confirms the conduction chain: "Supply chain financing reduces financing constraints, thus enhancing green innovation." This theoretically verifies the view that supply chain financing promotes green innovation by improving the way companies obtain funds.

5.2 Policy Implications

Based on the above conclusions, this paper proposes the following policy recommendations:

5.2.1 Promote the integrated development of supply chain finance and green finance

First of all, from the government's point of view, efforts should be made to promote the integrated development of supply chain finance and green finance. Government departments should encourage financial institutions to develop specialized green supply chain financing products, adopt the model of "data credit+ physical mortgage" for green and low-carbon industries, and guide funds to enterprises that are willing and capable of green transformation. Empirical evidence shows that for every additional unit in supply chain financing, the number of enterprises applying for green patents will increase by about 7%. Policy measures should make full use of this positive effect.

5.2.2 Address corporate heterogeneity through differentiated support policies.

Secondly, from the perspective of enterprises, we should pay attention to the heterogeneity of enterprises and formulate different support policies. For non-state-owned enterprises, the focus should be on improving their participation and the ability to benefit from supply chain financing. This can be achieved by establishing a public service platform for supply chain financing and introducing government-supported financing guarantee institutions to solve the credit problem. For enterprises with decentralized ownership structure, it is necessary to improve the governance mechanism of the board of directors and strengthen the supervision of green investment decisions. This ensures that external financing is oriented to green innovation, and at the same time avoids that a long decision-making chain will reduce the efficiency of financing conversion.

5.2.3 Strengthen the transmission efficiency of financing constraint relief.

Third, from the perspective of financial institutions, we should try to further improve efficiency and help enterprises reduce the trouble of finding money. Financial institutions should improve the financing process of supply chain. They can use the good reputation of core enterprises and real transaction data to lower the threshold of loans and reduce the capital cost of SMEs. At the same time, enterprises should actively use supply chain financing to improve their way of raising funds. The released funds should go into green R&D activities to create a virtuous circle: "better funds → more innovation investment → better performance". The mechanism test shows that reducing financing problems is the main way for supply chain financing to help green innovation. Policy design should focus on making this road easier and smoother.

5.2.4 Improve green information disclosure and sharing mechanisms.

Finally, it is very important for regulators to improve the disclosure and sharing of environmental information. The authorities should encourage the establishment of supply chain financing information platform. The platform will collect various types of data, such as orders, logistics, payment and the company's environmental performance. This will help to reduce the information gap between financial institutions and green projects. At the same time, enterprises should be encouraged to voluntarily demonstrate their progress in green innovation and how they use the funds they receive. This will make the market more confident and attract more green capital.

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