The Role of Supply Chain Finance in Facilitating Green Innovation: An Empirical Study of Core Enterprises in the Era of Digital Transformation

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Abstract. With the rapid development of China's economy, supply chain finance, as an important financial service model, plays an important role in solving enterprise financing problems and promoting the coordinated development of industrial chains. Especially in the context of the current digital transformation, the deep integration of supply chain finance and digital technology provides new impetus for green innovation. Based on this background, this paper takes the core enterprises in the industrial chain as the research object. Through model design, it conducts in-depth discussion on the impact of supply chain finance on green innovation performance in the context of digital transformation, and uses empirical research to verify this impact. Through the main regression analysis and mediate analysis, this paper finds that in the context of the digital economy, supply chain finance can improve the green innovation performance of core enterprises, and the financing constraint plays the role of mediator. This conclusion remains valid after replacing the proxy variables with other robustness tests. Based on this, this paper puts forward a series of suggestions from the perspectives of core enterprises, financial institutions and small and medium-sized enterprises for promoting the development of digital supply chain finance, reducing financing constraints of Chinese core enterprises and improving the green innovation performance of Chinese core enterprises.

Keywords: Corporate Green Innovation, Financing Constraints, Digital Supply Chain Finance, Core Enterprises.

1. Introduction

The development of supply chain finance in China began in the early 21st century. Although there are differences in concept between China and the West and in China, the core of supply chain finance is to realize the organic integration of large, medium and small enterprises in the industry by integrating information flow, capital flow and other elements of the industrial chain, so as to meet the capital needs of the upstream and downstream of the industrial chain. This is a financial service model. The key to supply chain finance activities is the credit of core enterprises. Through the core enterprise's own behavior as a guarantee, other member enterprises with real transactions can obtain the corresponding trade financing. Whether it is the goal of carbon peak and carbon neutrality or the construction of an environmentally friendly society, enterprises are required to innovate green technology, produce green results and realize green innovation. However, companies often lack intrinsic incentives to adopt green behaviors (Liao et.al, 2024) [1]. Supply chain finance, especially in the context of digital transformation, as a new financing model, can better meet the financing needs and risk control needs of middle and downstream enterprises in the industrial chain, increase information transparency, reduce financing constraints, thus easing the capital pressure of green research and development investment, and ultimately promote the green innovation of enterprises (Wang et.al, 2022, Zeng, 2023) [2,3].

The background of digital transformation is a macro concept, and the green innovation of enterprises is a micro perspective, which shows that the mechanism between the two is subtle and complex. In the existing literature, the role of supply chain finance in alleviating the financing difficulties and expensive problems of SMEs has been extensively and deeply studied (Liu and Guo, 2022, Tao, 2022, Wang, 2023) [4,5,6], and the relevant policies mostly focus on how to promote the

development of smes through supply chain finance services. However, little attention has been paid to the role of core enterprises that play a leading role in the supply chain in promoting green innovation throughout the industrial chain.

This paper breaks through the traditional research perspective, focuses on core enterprises, and discusses how supply chain finance influences core enterprises to promote the green innovation performance of the entire supply chain under the background of digital transformation. This research not only enriches the theory of the relationship between supply chain finance and enterprise innovation, but also provides a new thinking Angle for policy makers. Through empirical analysis, this paper reveals the positive impact of supply chain finance on the green innovation performance of core enterprises and the intermediary role of financing constraints, which provides strong evidence support for the optimization of supply chain finance policies.

2. Mechanism analysis and model design

2.1. Mechanism analysis and research hypothesis

2.1.1. The impact of digital supply chain finance on innovation performance

There are many relevant studies on digital supply chain finance on innovation performance. For example, Jiang et al. (2022) pointed out that supply chain finance plays a key role in promoting innovation of new energy enterprises by taking green innovation of new energy enterprises as the dependent variable [7]. Lv and Xu (2023) took manufacturing enterprises as research objects and found that supply chain finance can continuously promote the innovation and development of enterprises, especially for enterprises in the east, central and high customer concentration [8].

Based on the literature review, this paper proposes the first hypothesis:

H1: Digital supply chain finance has a positive effect on green innovation.

2.1.2. Intermediation effect of financing constraints

Compared with other research and development activities, the cost of innovation activities is more concentrated on intangible expenses such as the salary of researchers, and the innovation benefits are difficult to estimate, unstable, lack of internal financing motivation, and high external financing costs. The action mechanism of supply chain finance on finance is relatively complex, and it is a fundamental change to improve finance (Song and Zhu, 2024) [9]. From the perspective of credit system, supply chain finance is based on the credit of core enterprises, which reflects the market's incentive to enterprise credit, and will help enterprises to improve their own credit for future financing activities.

Based on the above analysis, this paper proposes the second hypothesis:

H2: Financing constraints play an intermediary role in the positive impact of digital supply chain finance on corporate green innovation.

2.2. Variable Selection

2.2.1. Dependent variable: green innovation

Compared with innovation input, it is generally believed that innovation output is more representative of innovation effect. For example, Yan et al. (2024) divided the number of green patents of listed enterprises according to the green patent list of the World Intellectual Property Organization, and chose the ratio of the number of green patent grants to the number of applications to represent the green innovation performance [10]. Based on this, this paper also selects the number of green patent grants as the proxy variable, and replaces it with the number of green patent applications in the robustness test.

2.2.2. Independent variable: digital supply chain finance

As for the measurement method of supply chain finance, this paper selects the ratio of short-term loans, notes payable and accounts payable to total assets (Ying and Hai, 2023) [11] as the proxy variable of supply chain finance (SCF), while accounts receivable/operating income (Song et al., 2021)

[12] as the proxy variable of robustness test. As for the measurement of enterprise digitalization level, Yuan et al. (2021) used national policy documents as text base, screened out digital dictionaries according to frequency, and then carried out text analysis on annual reports [13]. In this paper, word frequency analysis is used to quantitatively represent the digitalization level (DCG) of enterprises, and then the product of digitalization level and supply chain finance (SCF) is used to represent the digital supply chain finance level.

2.2.3. Intermediary variable: financing constraint

Financing constraints are affected by a variety of financial indicators, so they are often represented by a variety of financial data, such as KZ index, WW index, SA index, etc. Considering the characteristics of Chinese enterprises, many domestic scholars have adjusted the measurement method of financing constraints. Yu et al. (2019) uses the ratio of interest expense and debt to represent financing constraints, and the larger the value, the larger the financing constraints [14]. This paper refers to this measurement method.

2.2.4. Control variables

In order to control the influence of other potential variables on the dependent variables and increase the credibility of the results, this paper sets corresponding control variables by referring to the research results of some scholars. The longer an enterprise is established, the more market experience and resources it will have, and the stronger its awareness of innovation will be (Xu et al., 2023) [15]. Enterprise scale, similar to the year of enterprise establishment, large enterprises tend to have more capabilities and resources to participate in innovation activities (Li and Gong, 2023) [16]. The number of employees, total assets and sales revenue of the enterprise can all represent the enterprise scale. In this paper, the logarithm of total assets (millions) of the enterprise is selected to represent the enterprise scale. Asset-liability ratio and asset structure have been proved to have an inverted U-shaped effect on enterprise innovation (Yang and Qin, 2020) [17]. Corporate governance structure, the proportion of independent directors of a company can represent its governance structure, and independent board of directors affects the implementation of corporate innovation decisions (Sierra-Morán et al., 2024) [18]. The core variables of this paper and their proxy variables are shown in Table 1:

Table 1. Variable description

Category	Name	Symbol	Proxy Variables
Dependent variable	Green innovation	GI	Ln (Number of green patents granted +1)
Independent variable	Digital supply chain finance	DSCF	DCG*SCF
Intermediary variable	Financing constraint	FC	Interest debt ratio
Control variables	Age	Age	Ln (Age+1)
	Size	Size	InCapital
	Asset-liability ratio	Lev	Total liabilities at year-end/total assets at year-end
	Proportion of independent directors	Indep	Number of independent directors/Directors

2.3. Model design

According to H1 proposed above: digital supply chain finance has a positive effect on green innovation. The regression model is constructed as follows:

$$GI_{i,t}=\beta_0+\beta_1 DSCF_{i,t}+\beta_2 Age_{i,t}+\beta_3 Size_{i,t}+\beta_4 Lev_{i,t}+\beta_5 Indep_{i,t}+\text{Year}+\text{Firm}+\varepsilon_{i,t} \quad (1)$$

GI is the dependent variable green innovation performance; DSCF is the dependent variable digital supply chain finance; Age, Size, Lev and Indep are the four control variables; Year represents the year fixed effect; Firm represents the individual fixed effect; ε is the random error term. In model (1), hypothesis 1 is successfully tested if β1 is significantly greater than 0.

In order to test the mediating role of H2: financing constraints, this paper draws on Wen et al. (2004) [19] 's method for testing the mediating effect, and constructs a model as follows:

$$FC_{i,t}=\beta_0+\beta_1 DSCF_{i,t}+\beta_2 Age_{i,t}+\beta_3 Size_{i,t}+\beta_4 Lev_{i,t}+\beta_5 Indep_{i,t}+\text{Year}+\text{Firm}+\varepsilon_{i,t} \quad (2)$$

$$GI_{i,t}=\beta_0+\beta_1 DSCF_{i,t}+\beta_2 FC_{i,t}+\beta_3 Age_{i,t}+\beta_4 Size_{i,t}+\beta_5 Lev_{i,t}+\beta_6 Indep_{i,t}+\text{Year}+\text{Firm}+\varepsilon_{i,t} \quad (3)$$

When the β_1 of model (1) is significantly greater than 0, the β1 of model (2) is significantly less than 0, the β_1 of model (3) is significantly greater than 0 and smaller than the β_1 of model (1), and the β_2 of model (3) is significantly less than 0, H2 is established.

3. Empirical analysis

3.1. Data source

Enterprises listed on Shanghai and Shenzhen A-shares generally have higher commercial credit, larger scale, and are often at the core of the supply chain (Liang and Fang, 2024) [20]. At the same time, considering that the account receivable financing subject was officially disclosed in 2019, we believe that starting from the fourth quarter of 2019, the Shanghai and Shenzhen listed enterprises of this subject are steadily and continuously disclosed as core enterprises for supply chain finance activities, and as of September 28, 2024, A total of 3712 Shanghai and Shenzhen A-share enterprises meet the above conditions. To sum up, this paper takes the A-share listed enterprises in Shanghai and Shenzhen from 2019 to 2023 as the overall sample, takes the continuous disclosure of accounts of "receivables financing" as the verification method for screening core enterprises, removes ST, ST*, the financial industry, and samples with incomplete data, and selects A total of 1,325 core enterprises and 6,625 samples, with data from CSMAR.

3.2. Descriptive statistics and correlation analysis

3.2.1. Descriptive statistics

In this paper, 1325 core enterprises and 6625 samples were screened, and the panel data were processed by 1% and 99% of the so-called two-sided processing to reduce errors. The specific descriptive statistics are shown in Table 2: The number of green patent grants for enterprises is calculated using the logarithmic method of adding 1. The mean value is 0.465, the standard deviation is 0.841, and the value ranges from 0 to 3.714. The mean value of enterprise digitization level is 1.852, the standard deviation is 1.341, and the value ranges from 0 to 5.037. The corresponding independent variable, digital supply chain finance, has a mean value of 0.536 and a standard deviation of 0.472, ranging from 0 to 2.065. The mean value and standard deviation of financing constraints of intermediary variables are 0.0172, 0.0101, the minimum value is 0.000669, and the maximum value is 0.0461. The difference of financing capabilities of different enterprises can be more clearly observed after the proxy variable of financing constraints is enlarged by 100 times, and the value ranges from 0.0669 to 4.607.

Table 2. Descriptive statistics

	(1)	(2)	(3)	(4)	(5)
VARIABLES	N	mean	sd	min	max
GI	6,625	0.465	0.841	0	3.714
DCG	6,625	1.852	1.341	0	5.037
DSCF	6,625	0.536	0.472	0	2.065
FC	6,625	0.0172	0.0101	0.000669	0.0461
100*FC	6,625	1.722	1.012	0.0669	4.607
Size	6,625	9.121	1.327	6.810	13.00
Age	6,625	3.107	0.253	2.398	3.664
Lev	6,625	0.510	0.161	0.163	0.896
Indep	6,625	37.83	5.378	33.33	57.14

Note: 1% and 99% indentation were performed for all continuous variables

3.2.2. Correlation analysis

(1) Pearson correlation analysis

The correlation analysis of each variable in the sample is shown in Table 3. The absolute values of the correlation coefficients of independent variable, intermediary variables and four control variables on the green innovation of the dependent variable range from 0.0128-0.1980, all of which are less than 0.5, and most of the variables are significant at the significance level of 1%, which indicates that there is no obvious collinearity problem between the variables. The correlation coefficient between the dependent variable and the dependent variable is 0.1232, which is significant at the significance level of 1%, which can preliminarily indicate that digital supply chain finance (DSCF) has a significant positive impact on the green innovation performance (GI) of enterprises, that is, the correctness of model 1. The correlation coefficients between digital supply chain finance (DSCF), green innovation (GI) and financing constraint of intermediary variable (FC) are -0.1060 and -0.1246, respectively, and are all significant at the 1% level, which can also preliminarily prove hypothesis H2, that is, the intermediary role of financing constraint between the independent variable and the dependent variable.

Table 3. Pearson correlation analysis

	GI	DSCF	FC	Size	Age	Lev	Indep
GI	1						
DSCF	0.1232***	1					
FC	-0.1246***	-0.1060***	1				
Size	0.1980***	0.0307**	0.0246**	1			
Age	-0.0659***	0.0159	0.0617***	0.1738***	1		
Lev	0.0924***	0.3040***	0.2315***	0.3914***	0.1513***	1	
Indep	0.0128	0.0467***	-0.00170	0.0253**	-0.0535***	0.0266**	1

Note: *, ** and *** represent significant levels of 10%, 5% and 1% respectively

(2) Variance inflation factor

In order to further determine whether there is multicollinearity between variables, VIF analysis is performed on the sample data. As can be seen from Table 4, the average VIF coefficient between each variable and the interpreted variable green innovation is 1.16, which is far less than the judgment standard of 10, which can prove that there is no multicollinearity between each variable and the model is relatively robust.

Table 4. VIF analysis

Variable	VIF	1/VIF
DSCF	1.16	0.861304
FC	1.11	0.902872
Size	1.22	0.817978
Age	1.04	0.957468
Lev	1.44	0.693142
Indep	1.01	0.993633
Mean VIF	1.16	

(3) The Hausman test

The Hausman test can be used to determine whether the panel data is a fixed effects model or a random effects model. Table 5 shows the results of the Hausman test. After processing the sample data, it is found that Prob>chi2 is 0.0000, indicating that the null hypothesis is rejected at 1% confidence level, that is, the model in this paper belongs to a fixed effects model rather than a random effects model.

Table 5. The Hausman test

	FE	RE
DSCF	-0.0284893	0.0489845
Size	0.0912159	0.132733
Age	0.3568857	-0.0332936
Lev	0.0883083	0.0374837
Indep	0.0012151	0.0013868
Chi2(5)	63.58	
Prob>chi2	0.0000	

3.3. Main regression analysis

The main regression results of this paper are shown in Table 6:

First, model (1) is used to verify H1, and the regression results were as follows. The regression coefficient β_1 of digital supply chain finance (DSCF) and green innovation (GI) is 0.219, which is positive and significant at 1% confidence level, indicating that every 1% increase in the level of digital supply chain finance can increase the number of green patent grants by 0.219%, thus verifying hypothesis 1.

In order to verify the mediating role of financing constraints, a regression analysis is first conducted on digital supply chain finance and financing constraints, and it is found that the β_1 in model (2) is -0.004 and significant at the significance level of 1%, which indicates that digital supply chain finance has a significant negative correlation with financing constraints, and model (2) is correct.

Then model (3) is verified, and the regression results are shown in the following table. It is found that in model (3), the regression coefficient β_2 between financing constraints and green innovation is -9.886 and is significant at the 1% level, while the regression coefficient β_1 between digital supply chain finance and green innovation is 0.176 and is positive, which is smaller than β_1 (0.219) in model (1). To sum up, the intermediary role of financing constraints can be verified. The greater the financing constraints, the more detrimental it is to enterprises' green innovation.

Table 6. Principal regression result

	(1)	(2)	(3)
VARIABLES	GI	FC	GI
FC			-9.886***
			(-9.55)
DSCF	0.219***	-0.004***	0.176***
	(9.77)	(-16.46)	(7.74)
Size	0.138***	-0.001***	0.129***
	(16.65)	(-7.99)	(15.55)
Age	-0.345***	0.001***	-0.329***
	(-8.54)	(2.83)	(-8.17)
Lev	-0.076	0.021***	0.134*
	(-1.06)	(24.41)	(1.80)
Indep	-0.001	0.000	-0.001
	(-0.31)	(0.29)	(-0.32)
Constant	0.219	0.012***	0.338**
	(1.44)	(6.51)	(2.22)
Observations	6,625	6,625	6,625
Firm effect	YES	YES	YES
Year effect	YES	YES	YES
r2_a	0.0630	0.0964	0.0751
F	90.14	141.9	90.31

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

3.4. Robustness test

In order to test the robustness of the empirical results, this paper will change the proxy variables of the independent variable and the dependent variables, and then analyze the regression results.

3.4.1. Change the proxy variable of digital supply chain finance

In this paper, accounts receivable/operating income (DSCF2) is used as a proxy variable for independent variable in the robustness test, and the results of regression analysis are shown in Table 7. β_1 in model (1) is 0.162 and significant; β_1 in model (2) is -0.001 and significant; β_2 in model (3) is -10.518 and significant; β_1 is 0.149 and smaller than β_1 in model (1) and significant. In summary, it can be proved that hypothesis 1 and hypothesis 2 are still valid after changing the proxy variables of digital supply chain finance, which proves the robustness of the empirical results.

Table 7. Principal regression result

	Model (1)	Model (2)	Model (3)
VARIABLES	GI	FC	GI
FC			-10.518***
			(-10.36)
DSCF2	0.162***	-0.001***	0.149***
	(11.21)	(-7.49)	(10.29)
Size	0.145***	-0.001***	0.136***
	(17.38)	(-7.44)	(16.31)
Age	-0.340***	0.001***	-0.323***
	(-8.42)	(2.87)	(-8.05)
Lev	0.133**	0.016***	0.310***
	(1.97)	(20.04)	(4.48)
Indep	-0.000	-0.000	-0.000
	(-0.09)	(-0.25)	(-0.17)
Constant	0.047	0.012***	0.180
	(0.30)	(6.66)	(1.17)
Observations	6,625	6,625	6,625
Firm effect	YES	YES	YES
Year effect	YES	YES	YES
r2_a	0.0672	0.0673	0.0814
F	96.48	96.22	98.50

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

3.4.2. Change of proxy variables of green innovation

In this paper, the number of green patent applications (GI2) is used as the proxy variable of the dependent variable in the robustness test. The regression analysis results are shown in Table 8. β_1 in model (1) is 0.306 and significant; β_1 in model (2) is -0.004 and significant; β_2 in model (3) is -11.346 and significant; β_1 is 0.257 and smaller than β_1 in model (1) and significant. In summary, it can be proved that hypothesis 1 and hypothesis 2 are still valid after changing the proxy variables of the dependent variables, which proves the robustness of the empirical results.

Table 8. Change the proxy variable of green innovation

	Model (1)	Model (2)	Model (3)
VARIABLES	GI2	FC	GI2
FC			-11.346***
			(-9.86)
DSCF2	0.306***	-0.004***	0.257***
	(12.30)	(-16.46)	(10.18)
Size	0.151***	-0.001***	0.142***
	(16.42)	(-7.99)	(15.33)
Age	-0.444***	0.001***	-0.425***
	(-9.89)	(2.83)	(-9.51)
Lev	-0.203**	0.021***	0.036
	(-2.55)	(24.41)	(0.44)
Indep	0.000	0.000	0.000
	(0.08)	(0.29)	(0.08)
Constant	0.465***	0.012***	0.596***
	(2.74)	(6.51)	(3.52)
Observations	6,625	6,625	6,625
Firm effect	YES	YES	YES
Year effect	YES	YES	YES
r2_a	0.0692	0.0964	0.0821
F	99.48	141.9	99.43

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

4. Conclusions

4.1. Research conclusion

This paper takes the relevant data of Shanghai and Shenzhen A-share listed enterprises from 2019 to 2023 as the sample source for empirical analysis, and takes whether to continuously disclose accounts of "receivables financing" as the verification method for screening core enterprises. The main conclusions are as follows:

First, digital supply chain finance can significantly increase the green innovation performance of China's core enterprises; Second, digital supply chain finance can significantly ease the financing constraints of China's core enterprises; Third, digital supply chain finance can further promote the development of green innovation performance of China's core enterprises by easing financing constraints. Compared with Chinese smes' own financing constraints, which are difficult to solve and the financing proceeds are more used to solve operational problems than green innovation, this study focuses on Chinese core enterprises, because they are easier to achieve the development of green innovation performance.

4.2. Policy suggestion

4.2.1. Promote the development of digital supply chain finance

In order to promote the development of digital supply chain finance, core enterprises should accelerate digital transformation, establish a sound internal control system, improve supply chain transparency and traceability, and actively participate in industry self-discipline. Financial institutions should provide customized services, strengthen cooperation with governments and enterprises, and improve the technological content of services. SMEs should deepen cooperation with core enterprises, enhance information transparency and credibility to enhance their attention and rights in supply chain

finance, and adopt new technologies to improve the level of informatization and integrate into the digital supply chain system.

4.2.2. Proposals to ease financing constraints for China's core enterprises

In order to ease the financing constraints of China's core enterprises, core enterprises need to strengthen standardized management, improve the level of information disclosure, cooperate with upstream and downstream enterprises, and improve financing capacity. Financial institutions need to innovate supply chain financial products, improve the ability to identify credit risks, and build a supply chain financial ecosystem. SMEs can obtain financing support by strengthening cooperation with core enterprises and using the credit and influence of core enterprises. In addition, they should also focus on improving their operational efficiency and credit rating, and reduce the difficulty of financing by establishing a good credit history.

4.2.3. Suggestions for increasing green innovation performance of core enterprises in China

In order to increase the green innovation performance of China's core enterprises, core enterprises should strengthen research and development capabilities, integrate green innovation into corporate strategies, and optimize capital allocation to support green projects. Financial institutions should develop green financial products, strengthen risk assessment, and support green innovation projects. SMEs should pay attention to green innovation ability, participate in green innovation activities of core enterprises, and strive for policy and financial support.

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