Fintech development and green innovation -- Evidence from China

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Abstract. Based on the data of Chinese A-share listed companies from 2011 to 2018, We study the impact of the development of fintech on enterprises' green innovation. In the empirical analysis, we use the two-way fixed effect model to address fintech's influence on green innovation, then using mediation effect test and robust test to further analyze and verify this effect. This study finds that the development of fintech can significantly promote the level of green innovation of enterprises. The mechanism could be that the information asymmetry: 1) reduces the degree of information asymmetry; 2) alleviates the financing constraints; 3) improves the willingness to invest in innovation.

Keywords: Fintech; Enterprise green innovation; Bidirectional fixed effect model; Information asymmetry; R&D investment.

1. Introduction

"Emission Peak" has become a significant strategic target of China since being first launched in the 19th CPC National Congress. The fifth Plenary Session of the 19th CPC Central Committee stresses the need to promote comprehensive green transformation of economic and social development, accelerate green and low-carbon development. Enterprise, the main implementer of green innovation and the main user of natural resources, should carry out green technology innovation activities to realize the transformation of China's economic development mode. The Action Plan for Peaking Carbon by 2030 clearly states that enterprises are supposed to be strengthened to play a leading role in innovation and supported to undertake major national green and low-carbon science and technology projects. Under the guidance of these policies, enterprises began to attach importance to green innovation, however, green innovation projects have high capital risks and uncertainties [1], resulting in information asymmetry including adverse selection and moral hazard [2]. Moreover, the traditional financial system is inclined to the rich, making micro-enterprises' green innovation activities face serious external financing problems [3]. All these issues seriously hinder enterprises from carrying out green innovation projects.

Fintech, the integration of cloud computing, blockchain and other digital technologies with the financial market, is dramatically changing China's economic development, as well as providing new possibilities for solving the financing difficulties of green innovation for enterprises. The powerful service capacity of fintech could optimize the efficiency of resource allocation in financial market and solve the financing difficulties of micro businesses in traditional financial market effectively. Therefore, fintech has become an important indicator to explore effects of regional fintech development on enterprise green technology innovation. After reviewing relevant literature, we find that existing documents mostly focus on the influence of policy regulations, internal and external stakeholder characteristics of enterprises and other factors on enterprises' green innovation behavior, a few involves the influence of regional fintech development on enterprises' green innovation activities.

This paper mainly addresses the following three questions: Can fintech promote green innovation in enterprises? If so, what are the mediating mechanisms for this influence? In addition, is there heterogeneity among patent types and regions? This study used a bidirectional fixed effects model to analyze 19909 samples from 2010 to 2018 and found that fintech can significantly promote green technology innovation in enterprises; Further research shows that fintech development can reduce the financing cost of enterprises by alleviating information asymmetry, and then improve their R&D investment to achieve the positive externality of "green innovation". Finally, regional fintech

development has a significant promoting effect on different types of green innovation patents and has a more significant promoting effect on green technology innovation of enterprises in regions facing more environmental pressure, which provides reference for the further improvement of relevant policies. This study helps to reveal the importance of fintech development for green transformation of enterprises and clarify the role of fintech on green innovation of enterprises.

In the following, we begin by reviewing the literatures related to fintech and green innovation, putting forward two hypotheses. Section 3 introduces the data source and research strategy of this paper. Section 4 is the basic empirical results and robustness test; Section 5 analyzes the adjustment mechanism and intermediary mechanism. Finally, Section 5 is the research conclusions

2. Literature review and hypotheses

We begin with the presentation of the literature on fintech and green innovation. This helps us to find out that information asymmetry may lead to financial constraints, further causing the reduction of enterprise innovation input, affecting enterprises' green innovation.

(1) Fintech, information asymmetry and enterprise green innovation

Green innovation, also known as environmental innovation, ecology innovation, sustainable innovation [4], is the combination of technological innovation and green ecological. It was first put forward by Braun&Wield, stating that green innovation is a general term for processes, technologies and products that improve energy efficiency, being the key link to coordinate enterprise performance improvement and environmental regulation [5]. Since then, scholars defined the concept of green innovation in different disciplines including environmental economics and innovation economics: equate green innovation to the new method formed through productions, services, or managements in the processes of reducing or avoiding pollution of the environment, and to the improvement of the environmental innovation or the environmental performance [6][7]. Although academia has yet to give an authoritative definition to it, the connotation is consistent: these concepts are all based on green technology, take green environmental protection as principle, regard green performance as the goal, apply improvement of the green products, technology, or management to every link of enterprise production and operation, thus realize the coordinated development of economy and environment of innovative technology.

From the perspective of external financing, enterprises' innovative activities tend to serious financing constraints. Innovation projects relies heavily on financing activities of enterprises because of a large capital demand, long cycle, high investment, high risk and strong uncertainty (Brav et al. , 2018; Hall, 2002) [8] [9]. However, the credit market tends to give priority to the supply of conservative and low-risk investment (Brown et al., 2012) [10] instead of enterprises' innovative investment, which makes enterprises' innovative activities prone to financing constraints (Ju Xiaosheng et al., 2013) [3]. Moreover, the R&D of enterprises' green innovation is suffering from financing constraints, too. Compared with general innovation activities, enterprises' green innovation activities have more obvious characteristics of long cycle and high risk, and enterprises are faced with high costs and risks of failure in the process of green transformation. Therefore, enterprises' green innovation R&D activities can be restrained. In addition, the developed level of financial market may have an important impact on enterprises' green innovation, because when enterprises are faced with insufficient internal financing, they will rely on external financing to provide financial support. Under the traditional financial market system, it is difficult for financial institutions to obtain the credit investigation records of small and micro enterprises. Further, due to the secrecy of specific information of enterprise innovation activities, it is even more difficult to understand the relevant situation of green innovation activities of small and micro enterprises. Therefore, in the process of green transformation, relevant groups often face relatively high financing threshold and financing discrimination, and finance lacks inclusiveness.

The development of fintech alleviates these problems to some extent. Fintech can figure out the comprehensive enterprise information, thus alleviating information asymmetry. Huang et al. (2018)

[11] found that Ant Financial would use non-financial information beyond the reach of traditional loan application for loan approval. Lin et al. (2013) [12] found that the social network relationship information of borrowers can be used for credit approval on Prosper lending platform. In the traditional mode of financial services, it is difficult to obtain the comprehensive information of enterprises, so banks and other financial institutions pay more attention to enterprises' hard assets that are available for mortgage (Qian Xuesong etc., 2019) [13], and ignore the enterprise's "soft power", such as green innovation ability, making those enterprises with few hard assets and huge potential for green be difficult to obtain financing, it hinders the green transformation of enterprises and is contrary to China's current economic development policy. Fintech, however, through big data, artificial intelligence, and other underlying technologies, can comprehensively sort out and analyze various financial service subjects and form an ecological map of the science and technology industry (Han Han, 2018) [14], which could effectively adjust the focus of enterprise loan approval and improve the accessibility of financial services to enterprises' green innovation.

While effectively reducing the information asymmetry between banks and enterprises and helping banks fully grasp the relevant information of enterprises, the development of fintech can also accelerate the speed of credit approval and lending of financial institutions (Fuster et al., 2019; Huang et al., 2018) [15] [16], thus easing financing constraints and reducing financing costs. This loan approval method based on the fintech can reduce the search, transaction, and matching costs effectively in the loan approval process (Goldfarb&Tucker, 2019) [17], improving financing efficiency, reducing financing costs, and alleviating financing constraints faced by enterprises in green innovation.

(2) Fintech, enterprise innovation input and enterprise green innovation

In the face of serious financing constraints, enterprises are inclined to reduce R&D investment, while fintech can reduce the financing constraints faced by enterprises, alleviate the financial difficulties of the company, enrich its cash flow, and thus help increase enterprise innovation. Brown et al. (2009) [18] believed that large enterprises mainly rely on internal funds for R&D investment, while small and medium-sized enterprises lacking internal funds mainly conduct R&D financing through the stock market. However, in China, where the stock market mechanism is not yet sound, the financing constraints from the credit market will have a considerable impact on its innovation activities in the absence of internal financing. Buchak et al. (2018) [19] found that groups with difficulty in obtaining loans from traditional banks in the US housing mortgage market are more likely to obtain needed funds from fintech shadow banking. Therefore, the deep integration of technology and traditional financial market is bound to better serve relevant groups, further enrich the available funds of enterprises, and promote enterprises to use more funds for green innovation's R&D activities. Additionally, fintech is highly technology-oriented (Tang Song et al., 2022) [20], which makes enterprises more clearly understand the importance of their own scientific and technological innovation to obtain market competitive advantage and urges them to increase the intensity of R&D expenditure. Therefore, based on the above two aspects, by alleviating financing constraints and its own technology orientation, fintech can improve enterprises' willingness to green innovation, thus promoting enterprises' green innovation output, and ultimately promoting enterprises' green innovation activities. Based on the above analysis, this paper proposes the following two hypotheses:

Hypothesis 1: Regional fintech development can promote enterprise green innovation;

Hypothesis 2: The two mediating factors that regional fintech development promotes firm innovation are information asymmetry and firm innovation input.

3. Data and empirical strategy

(I) Sample selection and data sources

We used all A-share listed companies in Shanghai and Shenzhen stock markets from 2011 to 2018 as the original samples. The sample data of the original listed companies were all from the CSMAR

database and combined. Regional fintech development level data can be obtained through industrial and commercial registration information data. Green patent data of listed companies came from National Patent and Intellectual Property Office. The further screening process of the samples is as follows: First, we selected the four types of CSMAR industry codes and excludes the financial industry in order to prevent the interference of the financial indicators of the financial industry on the empirical results; Secondly, the samples of ST company during the research period were removed in order to obtain more accurate corporate financial data and avoid the interference of various indicators due to poor business operation. Thirdly, all continuous variables were winsorized up and down by 1% to eliminate the influence of extreme values on empirical analysis. Finally, after deleting the enterprise samples with missing variables, a total of 19,909 observed values of 3,340 enterprises were obtained.

(2) Calculation of regional fintech development level

We referenced the measurement of Song Min (2021), using the data from the national registered industrial and commercial enterprises through text analysis to identify the business of companies, including keywords like "financial science and technology", "cloud computing", "big data", "block chain", "artificial intelligence", "Internet of things", to get all the relevant industrial and commercial registration information of the companies. At the same time, we only retained the samples with the above keywords in the company name or business scope to avoid the coincidence character matching in the retrieval. In addition, we excluded the samples of companies that have been in business for less than one year or have abnormal operating conditions (such as suspension, dissolution, revocation, etc.) to further prevent the accuracy of fintech development indicators from the impact of the registration of "shell companies" . Moreover, the city level was summed up and obtain the fintech development level of the region represented by the natural logarithm of the number of fintech related companies in each city. Finally, the proportion of the number of fintech-related companies in each city to the number of all enterprises — Ratiao_fintech (a further measurement of the development level of regional fintech) was constructed in the robustness test to prevent the absolute number of enterprises from interfering with the results.

(3) Measure of enterprise green innovation

In this paper, the output of green innovation activities of listed companies in green environment is measured by the natural logarithm lnGPall, which is the sum of the number of green invention patents granted by listed companies and the number of green utility model patents granted by listed companies. In the later robustness analysis, green invention patents and green utility model patents will be distinguished and discussed.

(4) Empirical model setting

This paper intends to construct a two-way fixed effect model to address the influence of regional fintech development level on green innovation. The specific empirical analysis model is shown in Formula (1) :

$$lnGPall_{i,t} = \beta_0 + \beta_1 lnfintech_{i,t} + \beta_2 X_{i,t} + Year_{FE} + Industry_{FE} + \varepsilon_{i,t} \quad (1)$$

Where, the subscripts i and t indicate the enterprise and year respectively. Explained variable $lnGPall_{it}$ is the natural logarithm of the sum of green invention patents and green utility model patents granted by listed company i in the t year after adding 1. Core explanatory variable $lnfintech_{it}$ is the fintech development level of the city where listed company i is registered. The larger the value is, the higher the fintech development level of the city is. So β_1 is the core parameter to be estimated in this paper and is expected to be significant positive by theoretical hypothesis. X_{it} is the set of control variables at the enterprise level, and the specific settings are described later. In order to control the macro external environmental impact, we control the year fixed effect $Year_{FE}$. Equation (1) also uses $Industry_{FE}$ to control the fixed effect of the firm and industry, considering the interference of the potential invariant factors of the firm and industry on the causal inference in this paper. ε_{it} is the random disturbance term of the model. Finally, all statistical inferences in this paper are discussed based on heteroscedasticity robust standard error to prevent heteroscedasticity.

(5) Selection and setting of control variables

Referring to the standard practices of existing literature, the control variables selected in this paper include : (1) The enterprise scale (Size), measured by the natural logarithm of the total assets of the listed company at the end of the year; (2) Corporate asset-liability ratio (Leverage), depicted by the proportion of total liabilities in total assets of listed companies in that year; (3) Enterprise age (Age) is measured by the company's listing Age; (4) Business performance (ROA), which is measured by the return on assets of listed companies in the current year; (5) Size of fixed assets (Fix), measured by the proportion of fixed assets of listed companies in that year; (6) Cash ratio (Cash), which is measured by the ratio of cash held by listed companies in the current year; (7) Board independence (Indratio), measured by the proportion of independent directors in listed companies in the year; (8) Management shareholding (Mshare), which is measured by the shareholding ratio of the management of the listed company in the current year; (9) Ownership concentration (Top1), measured by the shareholding ratio of the largest shareholder of the listed company in that year; (10) Enterprise ownership (SOE), a dummy variable, 1 if the listed company is a state-owned enterprise, 0 otherwise; (11) Growth rate of operating income (Growth).

(6) Descriptive statistics of variables

The large standard deviation of green innovation indicates that the R&D investment intensity of different companies varies greatly and fluctuates greatly, which can also be seen from the maximum and minimum values. In terms of regional financial development level, the maximum value is 9.954, the minimum value is 3.466, and the mean value is 3.878, slightly higher than the median of 3.466, indicating that there are great differences in the level of financial development in different regions and the financial development is unbalanced. The specific results are shown in Table 1.

Table 1. Descriptive statistics of variables

Variable	Sample size	Average	Standard deviation	Minimum value	Median	Maximum
lnGPall	19909	0.316	0.733	0.000	0.000	6.771
lnfintech	19909	3.878	2.451	0.000	3.466	9.954
Size	19909	22.085	1.288	19.552	21.909	26.231
Leverage	19909	0.416	0.210	0.032	0.403	0.936
Age	19909	9.400	7.196	0.000	8.000	26.000
ROA	19909	0.527	0.449	-0.581	0.448	2.696
Fix	19909	0.211	0.161	0.002	0.177	0.716
Cash	19909	1.207	2.028	0.046	0.579	24.524
Indratio	19909	39.092	10.674	0.000	37.500	66.667
Mshare	19909	14.343	20.753	0.000	0.521	70.495
Top1	19909	0.351	0.149	0.082	0.331	0.758
SOE	19909	0.346	0.476	0.000	0.000	1.000
Growth	19909	15.66	32.328	-57.228	11.05	166.265

4. Results

(1) Analysis of benchmark regression results

The benchmark regression results of the above empirical model Formula (1) are shown in Table 2, including the stepwise regression results of the panel fixed effect model in this paper. The explained variables are the natural logarithm of the number of green patents granted by listed companies in the current year. No matter under what kind of control, all models estimated coefficients with the core of the variables under the 1% level of statistically significant positive, meaning the financial development of science and technology innovation of the enterprise there is significant positive influence on green innovation. Therefore, hypothesis 1 in this paper is verified.

Table 2. The impact of fintech development on enterprise green innovation

VARIABLES	OLS lnGPall	FE_1 lnGPall	FE_2 lnGPall
lnfintech	0.024***	0.033***	0.025***
	(0.002)	(0.003)	(0.003)
Size			0.173***
			(0.007)
Leverage			0.133***
			(0.031)
Age			-0.014***
			(0.001)
ROA			0.026**
			(0.012)
Fix			-0.216***
			(0.038)
Cash			-0.006***
			(0.002)
Indratio			0.001*
			(0.001)
Mshare			-0.000
			(0.000)
Top1			-0.151***
			(0.037)
SOE			0.013
			(0.013)
Growth			-0.000***
			(0.000)
YEAR FE	NO	YES	YES
INDUSTRY FE	NO	YES	YES
Observations	19, 909	19, 908	19, 908
R-squared	0.006	0.064	0.143

Note: The observed values are at the enterprise level. ***, ** and * are significant at the statistical level of 1%, 5% and 10%, respectively. The values in parentheses are heteroscedasticity robust standard error. 'YES' indicates that the fixed effect is controlled, and 'NO' indicates that the fixed effect is not controlled.

(2) Robustness test

Considering that the regional financial development on the macro level is hardly affected by the level of green innovation of micro enterprises, the endogenous problem caused by reverse causality is excluded. To further ensure the robustness of the empirical results, this test was carried out from the following aspects: change the green innovation measurement index, regional fintech development level measurement index, and model replacement.

First, replace the explained variable. The green innovation activity measured in this paper considers both the number of green invention patents granted and the number of green utility model patents granted. The innovation of the former is higher than the latter. This paper further divided the types of green innovation patents into green invention patents and green utility model patents, using model (1) to analyze the effect of pilot policies on green patent categories. To ensure the robustness of the results, the two are discussed separately in this part. As shown in Table 3, the explained variable lnGP in Column (1) is the natural logarithm of the number of green invention patents granted in the listing formula plus 1. In column (2), the explained variable lnGPnew is the natural logarithm of the number of green utility model patents granted in the year of listing formula plus 1. The estimated coefficients of lnfintech, the development level of the two core explanatory variables, are 0.017 and

0.018, both of which are significantly positive at the statistical level of 1%. Therefore, the conclusion of this paper is robust.

Table 3. Robustness test I: Green invention patents and utility model patents

VARIABLES	(1) lnGP	(2) lnGPnew
lnfintech	0.017***	0.018***
	(0.002)	(0.002)
Size	0.105***	0.135***
	(0.005)	(0.006)
Leverage	0.025	0.130***
	(0.020)	(0.027)
Age	-0.005***	-0.012***
	(0.001)	(0.001)
ROA	0.025***	0.017
	(0.009)	(0.011)
Fix	-0.116***	-0.168***
	(0.025)	(0.033)
Cash	-0.002*	-0.004**
	(0.001)	(0.002)
Indratio	0.001	0.001*
	(0.000)	(0.000)
Mshare	0.000	-0.000
	(0.000)	(0.000)
Top1	-0.087***	-0.099***
	(0.026)	(0.031)
SOE	0.013	0.002
	(0.008)	(0.011)
Growth	-0.000***	-0.000***
	(0.000)	(0.000)
YEAR FE	YES	YES
INDUSTRY FE	YES	YES
Observations	19908	19908
R-squared	0.106	0.122

Note: Similar to the note of Table 2. The control variables are the same as Table 2. Due to space constraints, it is not shown here.

Second, change the measurement of fintech development. In baseline regression, the level of fintech development is measured by the natural logarithm lnfintech of the number of fintech-related companies in each city. This paper further constructed the proportion of the number of fintech related companies in each city to the number of all enterprises, further measuring the development level of regional fintech to prevent the absolute number of enterprises from interfering with the results.

Table 4 illustrates all columns control for bidirectional fixed effects and other control variables. The explained variables of column (1) - column (3) are green patent, green invention patent and green utility model patent respectively. The estimation result of the core explanatory variable ratiao_Fintech is still significantly positive, and the conclusion is still maintained.

Table 4. Robustness test 2: Changing fintech development metrics

VARIABLES	(1) lnGPall	(2) lnGP	(3) lnGPnew
ratiao_fintech	0.123***	0.081***	0.091***
	(0.018)	(0.013)	(0.016)
Size	0.175***	0.107***	0.137***
	(0.007)	(0.005)	(0.006)
Leverage	0.124***	0.019	0.124***
	(0.031)	(0.020)	(0.027)
Age	-0.014***	-0.005***	-0.012***
	(0.001)	(0.001)	(0.001)
ROA	0.025**	0.024***	0.016
	(0.013)	(0.009)	(0.011)
Fix	-0.260***	-0.149***	-0.198***
	(0.037)	(0.024)	(0.032)
Cash	-0.005**	-0.002	-0.004**
	(0.002)	(0.001)	(0.002)
Indratio	0.001*	0.001	0.001
	(0.001)	(0.000)	(0.000)
Mshare	0.000	0.000	-0.000
	(0.000)	(0.000)	(0.000)
Top1	-0.135***	-0.076***	-0.088***
	(0.037)	(0.026)	(0.032)
SOE	0.020	0.018**	0.007
	(0.012)	(0.008)	(0.011)
Growth	-0.000***	-0.000***	-0.000***
	(0.000)	(0.000)	(0.000)
YEAR FE	YES	YES	YES
INDUSTRY FE	YES	YES	YES
Observations	19, 908	19, 908	19, 908
R-squared	0.141	0.103	0.121

Note: Similar to the note of Table 2. The control variables are the same as Table 2. Due to space constraints, it is not shown here.

Finally, since the number of patents granted by enterprises has no negative value, this paper also adopts panel Tobit model. Table 5 shows the estimation of all columns controls enterprise control variables and bidirectional fixed effects. Wherein, the explained variables in column (1) are green patent, the explained variables in column (2) are green invention patent, and the explained variables in column (3) are green utility model patent. The core explanatory variables are all fintech development lnfintech. The estimation result of panel Tobit is highly consistent with panel bidirectional fixed effect model. The conclusions of this paper are very stable.

Table 5. Robustness test 3: Panel Tobit model estimation

VARIABLES	(1) lnGPall	(2) lnGP	(3) lnGPnew
lnfintech	0.027***	0.020***	0.018***
	(0.004)	(0.003)	(0.004)
Size	0.092***	0.061***	0.079***
	(0.007)	(0.005)	(0.006)
Leverage	0.073**	0.043*	0.064**
	(0.032)	(0.023)	(0.030)

Age	-0.008***	-0.002	-0.008***
	(0.002)	(0.001)	(0.001)
ROA	0.001	0.006	0.000
	(0.013)	(0.010)	(0.012)
Fix	0.059	0.072**	0.007
	(0.040)	(0.028)	(0.037)
Cash	0.001	0.000	0.002
	(0.002)	(0.002)	(0.002)
Indratio	0.001***	0.001***	0.001***
	(0.000)	(0.000)	(0.000)
Mshare	-0.000	0.000	-0.000
	(0.000)	(0.000)	(0.000)
Top1	-0.068	-0.015	-0.066
	(0.045)	(0.032)	(0.041)
SOE	0.011	-0.000	0.014
	(0.021)	(0.014)	(0.018)
Growth	-0.001***	-0.000***	-0.000***
	(0.000)	(0.000)	(0.000)
YEAR FE	YES	YES	YES
INDUSTRY FE	YES	YES	YES
Observations	19, 909	19, 909	19, 909
Number of scode	3, 340	3, 340	3, 340

Note: Similar to the note of Table 2. The control variables are the same as Table 2. Due to space constraints, it is not shown here.

5. Further analysis and mechanism test

(1) Analysis of the regulation mechanism of carbon emissions

For China's green economic development, is there a "forced" effect on China's green economic development? In other words, for regions with high carbon emissions, will companies be empowered by fintech to carry out more green innovation? Based on this, this part analyzed the regulation mechanism of regional carbon emissions.

The carbon emission data used in this part came from China Carbon Accounting Database (CEADs). Considering that carbon emissions have a certain degree of skewness, provincial carbon emissions are logarithmic processed to analyze LNCO2.

The test of regional macro-carbon emission regulation mechanism is shown in Table 6: among them, the estimates in all columns control enterprise control variables and bidirectional fixed effects. The explained variable in column (1) is green patent, the explained variable in column (2) is green invention patent, and the explained variable in column (3) is green utility model patent. As can be seen from the estimated coefficients of the core interaction term lnfintech* lnCO2, the estimated coefficients of the three columns are significantly positive. This shows that the higher the regional carbon emissions, the stronger the impact of fintech development on enterprises' green innovation activities. Therefore, there is a significant adjustment mechanism for macro carbon emissions: enterprises in cities with high carbon emissions face more severe environmental pressure, and regional fintech development has a higher incentive for their green innovation.

Table 6. Test of regional macro-carbon emission regulation mechanism

VARIABLES	(1) lnGPall	(2) lnGP	(3) lnGPnew
lnfintech	0.098***	0.060***	0.072***
	(0.009)	(0.006)	(0.008)
lnco2	0.046***	0.015***	0.040***
	(0.007)	(0.004)	(0.006)
lnfintech*lnco2	0.025***	0.013***	0.019***
	(0.006)	(0.004)	(0.005)
Size	0.176***	0.099***	0.141***
	(0.008)	(0.006)	(0.007)
Leverage	0.055	0.014	0.049
	(0.037)	(0.023)	(0.033)
Age	-0.015***	-0.006***	-0.013***
	(0.001)	(0.001)	(0.001)
ROA	0.024*	0.024**	0.015
	(0.014)	(0.010)	(0.012)
Fix	-0.230***	-0.108***	-0.189***
	(0.044)	(0.029)	(0.039)
Cash	-0.008***	-0.004***	-0.006***
	(0.002)	(0.001)	(0.002)
Indratio	0.000	0.000	0.000
	(0.001)	(0.000)	(0.001)
Mshare	-0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)
Top1	-0.155***	-0.083***	-0.106***
	(0.043)	(0.029)	(0.037)
SOE	0.022	0.014	0.009
	(0.015)	(0.009)	(0.013)
Growth	-0.000**	-0.000**	-0.000**
	(0.000)	(0.000)	(0.000)
YEAR FE	YES	YES	YES
INDUSTRY FE	YES	YES	YES
Observations	13, 669	13, 669	13, 669
R-squared	0.146	0.107	0.124

Note: Similar to the note of Table 2. The control variables are the same as Table 2. Due to space constraints, it is not shown here.

(2) Mediation effect test

Why can regional fintech development significantly promote green innovation in enterprises? we argued that the development of fintech weakens the information asymmetry of external financial institutions and enterprises and alleviates the cash flow of enterprises are two important mechanisms. Based on this, the intermediate effect is further analyzed in this paper. Specific mediating effect model Settings are shown in Equations (2) and (3) :

$$Z_{it} = \gamma_0 + \gamma_1 lnfintech_{it} + \gamma_2 X_{it} + Year_{FE} + Industry_{FE} + \varepsilon_{it}^1 \quad (2)$$

$$lnGPall_{it} = \delta_0 + \delta_1 lnfintech_{it} + \rho Z_{it} + \delta_2 X_{it} + Year_{FE} + Industry_{FE} + \varepsilon_{it}^2 \quad (3)$$

Where, Z_{it} is the intervening variable. If the model satisfies that γ_1 in equation (3), δ_1 and ρ in equation (4) are all positive, then Z_{it} is considered to have a mediating role.

Firstly, the problem of enterprise information asymmetry was considered. Fintech uses big data, artificial intelligence, and other technologies to "empower" traditional financial institutions, quickly processes a large amount of micro-enterprise data, and fully digs out users' information, which not only reduce financing costs, but also alleviate the inherent information asymmetry between banks and enterprises, and ultimately alleviates the plight of "expensive financing" and "difficult financing" of relevant enterprises. Refer to song Min et al. (2021), based on the financial market microstructure literature and detailed transaction data, we built a proxy index of the degree of information asymmetry, using the liquidity ratios, illiquid ratios, and reverse index of the first principal component as the proxy variable of asymmetric information, the larger the index value is, the more serious the information asymmetry is.

Table 7 illustrates the mediating effect of fintech development on enterprise information asymmetry and Enterprise R&D investment. Similarly, column (1) is the estimation result of Equation (2), which can be seen from the lnfintech estimation coefficient. Its statistical level is significantly negative at 1%. Therefore, the regional fintech development level significantly reduces the degree of information asymmetry of investors such as internal and external financial institutions of enterprises. Equation (3) of the second step of the mediation effect test is shown in Column (2): The ASY estimation coefficient is -0.038, which is significantly positive at the statistical level of 1%, which means that the increase of enterprise information asymmetry will reduce enterprise green innovation. Therefore, the development of regional fintech alleviates the information asymmetry of enterprises, thus alleviating the financing constraints faced by enterprises in green innovation activities, and thus improving the green innovation performance of enterprises.

Second, we considered the company's R&D investment. The natural logarithm of R&D investment RDexp of listed companies in the same year was constructed as an intermediary variable. Column (3) is the estimation result of Equation (4), which can be seen from the lnfintech estimation coefficient. Its statistical level is significantly positive at 1%. Therefore, the development level of regional fintech has significantly increased the R&D investment of enterprises. Equation (3) of the second step of the mediation effect test is shown in Column (4) : The estimated coefficient of RDexp is 0.125, which is significantly positive at the statistical level of 1%. To sum up, the development of regional fintech reduces the financing constraints faced by enterprises and alleviates their cash flow, thus increasing the R&D investment of enterprises and creating conditions for green transformation of enterprises. Hypothesis 2 of this paper is verified.

Table 7. Analysis of mediation mechanism I: Information asymmetry & Enterprise R&D investment

	(1)	(2)	(3)	(4)
VARIABLES	ASY	lnGPall	RDexp	lnGPall
Z_{it}		-0.038***		0.125***
		(0.006)		(0.005)
lnfintech	-0.007**	0.025***	0.068***	0.016***
	(0.003)	(0.003)	(0.004)	(0.003)
Size	-0.346***	0.162***	0.851***	0.095***
	(0.008)	(0.007)	(0.010)	(0.008)
Leverage	0.649***	0.145***	-0.703***	0.307***
	(0.042)	(0.032)	(0.063)	(0.038)
Age	-0.017***	-0.016***	-0.023***	-0.015***
	(0.002)	(0.001)	(0.002)	(0.001)
ROA	0.025	0.029**	0.488***	-0.031*

	(0.015)	(0.013)	(0.031)	(0.016)
Fix	0.191***	-0.187***	-0.526***	-0.184***
	(0.046)	(0.039)	(0.075)	(0.047)
Cash	0.003	-0.006***	-0.008**	-0.002
	(0.003)	(0.002)	(0.004)	(0.002)
Indratio	-0.001	0.001	0.002**	0.001
	(0.001)	(0.001)	(0.001)	(0.001)
Mshare	0.002***	-0.000	0.000	-0.000
	(0.001)	(0.000)	(0.000)	(0.000)
Top1	0.530***	-0.126***	-0.425***	-0.131***
	(0.039)	(0.038)	(0.062)	(0.044)
SOE	0.071***	0.021*	-0.021	0.023
	(0.018)	(0.013)	(0.027)	(0.016)
Growth	0.001***	-0.000***	0.001***	-0.001***
	(0.000)	(0.000)	(0.000)	(0.000)
YEAR FE	YES	YES	YES	YES
INDUSTRY FE	YES	YES	YES	YES
Observations	18, 393	18, 393	16, 337	16, 337
R-squared	0.246	0.149	0.517	0.168

Note: Similar to the note of Table 2. The control variables are the same as Table 2. Due to space constraints, it is not shown here.

6. Conclusions

As analyzing above, we found that regional fintech development can significantly promote green innovation of enterprises. After a series of robustness tests, such as the change of fintech development level indicators, the change of green innovation measurement indicators and the change of model, the research conclusion still holds. Mechanism analysis shows that regional fintech development can reduce the degree of information asymmetry between financial institutions and enterprises, alleviate the financing constraints faced by enterprises, improve the willingness of enterprises to invest in innovation, and promote green innovation of enterprises. In addition, due to the existence of "forcing mechanism", the marginal role of fintech development in promoting green innovation of enterprises is more obvious in regions with high carbon emissions, that is, facing higher environmental pressure.

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