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Research on the Impact of Digital Transformation of Commercial Banks on Green Innovation

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Abstract: Digital technology helps to reduce costs and increase efficiency and expand the scope of financial services, this paper focuses on the digital transformation of commercial banks, using panel data and related indicators of A-share listed companies from 2010-2023 to analyse the impact of digital transformation of commercial banks on green innovation. Firstly, the fixed effect model is used to study the effect of digital transformation of commercial banks on green innovation, and the results show that digital transformation of commercial banks can significantly promote green innovation, and the conclusion still holds after a series of robustness tests. Secondly, we empirically explore the impact mechanism of commercial bank digital transformation on green innovation, and find that commercial bank digital transformation promotes green innovation by alleviating financing constraints and improving corporate governance, while the increase in the level of financial marketisation stimulates the investor's tendency to make profits, which leads to the flow of funds to short-term investment, thus inhibiting the green innovation that requires long-term financial support. In this paper, we study the heterogeneity in terms of region, the regional heterogeneity shows that the promotion effect of digital transformation of commercial banks presents the strongest gradient in the east, the second in the centre and the weakest in the west. This study both opens a new path for how commercial banks' digital transformation can empower green innovation and further expands the knowledge boundary of digital finance-driven green innovation research.

Keywords: Digital Transformation of Commercial Banks; Financing Constraints; Green Innovation; Financial Technology.

1. Introduction

Driven by the global digital wave and the "dual carbon" goal, green innovation is key to solving environmental issues, advancing social green transformation, integrating innovation-driven and green development strategies, and boosting coordinated economic-environmental development—making its effective promotion a critical issue. Green innovation faces challenges like difficulty securing stable financial support and financing exclusion, so guiding commercial banks to support green innovation projects is urgent. As a core part of the financial system, commercial banks are advancing digital transformation to enhance efficiency, optimize customer experience, strengthen risk management, and gain market advantages, which offers a new solution to resolve conflicts between the traditional credit model and green innovation demands.

Most of the existing literature examines the impact of digital transformation on the banks themselves. Yi-Liang Wang (2025), Yonghui Lian et al. (2025), and Shaolin Wang et al. (2025) explore the impact of digital transformation of commercial banks on their operational performance, retail lending business, and risk-taking capacity, respectively[1-3] . Shixin Dou and Kun Ji (2025) and Minfeng Lu (2023) discuss how commercial banks focus on the path innovation of financial services by building smart scenarios in the context of digital transformation[4][5] . Xing Tong and Su Yuhai (2024) investigated the differences and dynamic evolution of the digital transformation development of four major types of commercial banks and found that state-owned and joint-stock commercial banks have made significant progress in digital transformation, while urban and rural commercial banks have been relatively slow in the development of digital transformation, which lays a theoretical foundation for the analysis of bank heterogeneity in this paper[6] . Meanwhile, part of the literature focuses on exploring the impact of digital transformation of commercial banks on corporate innovation from the perspective of financing constraints, and Liu, Ziqiang and Feng, Qiusuo (2024), Han, Liangliang and Peng, Yi (2025), and Li, Xiaoxi et al. (2024) find that the digital transformation of commercial banks can alleviate the cost of corporate innovation by lowering the cost of corporate debt financing, lowering the cost of searching for information, processing cost and validation cost of the bank, and then alleviating the cost of corporate financing constraints to promote corporate innovation[7-9] . Past work mostly inspects how bank digitization affects banks themselves and reduces financing constraints, there are fewer explorations of other paths, which provides ideas for the mechanism analysis in this paper.

Based on the above, this paper takes the data of A-share listed companies from 2010 to 2023 as the basis to study the impact of digital transformation of commercial banks on green innovation. The marginal contribution of this paper is reflected in the following three aspects: first, it expands the current research scope by matching the digital transformation index of commercial banks of Peking University with the regions where the enterprises are located, and constructing a panel data of digital transformation of commercial banks at the enterprise level. Secondly, it supplements the existing path analysis by analysing two paths, namely, the level of corporate governance and the degree of financial marketisation, on the basis of the financing constraints path, which supplements the micro-action mechanism of commercial bank digitalisation on green innovation. Thirdly, to provide reference for the precise formulation of differentiated green financial policies, the heterogeneity analysis is carried out from the perspective of region. The digital transformation of commercial banks is a comprehensive and profound change that needs to be

promoted in a highly integrated manner across the board, so this study can provide reference for the formulation of differentiated green financial policies through heterogeneity analysis.

2. Theoretical Basis and Research Assumptions

2.1. The Direct Effect of Commercial Banks' Digital Transformation on Green Innovation

The functional view of finance holds that the core task of the financial system lies in the allocation of resources across time and space in an uncertain environment, and green innovation is naturally faced with high information costs and risk premiums due to the uncertainty of the technological route, the long return cycle, and the strong externality, and from the research and development of new technologies to the application of new products, the chain is long and the links are many, which not only requires sustained financial support, but also has the risk of investment failure. Wang Yao et al. (2019) proposed that although green innovation activities have the potential economic effect of cost reduction and quality improvement, the benefits often have a lag, and in the early stage of the need to invest a large amount of resources, which may have a certain degree of crowding out effect on the main business of the enterprise, the need to weigh the allocation of resources and strategic planning to ensure that in order to achieve the goal of sustainable development at the same time, to maintain the stable development of the main business[10] .

The digital transformation of commercial banks refers to the dynamic evolutionary process of improving the efficiency of resource allocation, optimising customer experience and strengthening risk management and control by taking big data, artificial intelligence, cloud computing, blockchain and other digital technologies as the core driving force, systematically reconstructing existing processes, products and risk control systems, and using data elements as the key assets. For the measurement of digital transformation of commercial banks, Xie Gloria et al. (2022) constructed a set of comprehensive index system based on the three dimensions of strategy, business and management, which has become an authoritative quantitative method for assessing the degree of digital transformation of commercial banks in China, and this paper adopts this index to measure the level of digital transformation of commercial banks[11] .

It can be seen that the digital transformation of commercial banks is not only the iterative upgrading of technical tools, but also a systematic change covering strategy, organisation, business and ecology. Through big data, artificial intelligence and other digital technologies, commercial banks are able to capture and cross-validate corporate carbon emissions, patents and ESG data in real time, which can effectively reduce the problem of ex ante adverse selection and ex post moral hazard, and then directly improve the accuracy of green project identification and risk pricing efficiency, which can help banks to achieve the penetrating supervision of the use of corporate green funds. From this, it can be proposed:

Hypothesis 1: The digital transformation of commercial banks has a positive direct effect on green innovation.

2.2. Indirect Effect of Digital Transformation of Commercial Banks on Green Innovation

(1) Mediating effect of financing constraints

The alleviation of enterprise financing constraints is conducive to the enhancement of green innovation. According to the theory of financing constraints, igher external financing premiums force enterprises to cut green R&D due to fund shortages. Thus, easing such constraints not only expands direct funding for green innovation but also raises enterprises' likelihood and intensity of green tech innovation by reducing capital costs and enhancing risk tolerance. Green innovation demands substantial human and financial resources, which internal operational funds alone cannot cover, making external funds essential. Commercial banks are the primary fund source here.

Traditional finance has high thresholds, high costs, and tight quotas, and the digital transformation of commercial banks breaks the barriers of traditional finance, which can alleviate the financing constraints by reducing the cost of financing and expanding the quantity of financing, and then provide sufficient financial support for corporate green innovation. Zhang Ocean and Zhao Jing (2024) pointed out in their study that commercial bank digital transformation alleviates the enterprise investment and financing term mismatch and reduces the financing premium by regulating the amount of short-term enterprise loans, improving the level of corporate governance, thus reducing the enterprise financing constraints and facilitating the access of small and micro enterprises to funds for green innovation activities[12] . At the same time, the digital transformation of commercial banks has expanded the population of financing available through the deployment of big data risk control models and online second credit platforms. Meanwhile, dynamic quota management based on real-time risk scoring allows banks to dare to provide longer-term funding to green projects, and the alleviation of financing constraints has provided enterprises with stable cash flow and long-term funding, which has in turn strengthened their willingness and ability to innovate in a green way. This leads to:

Hypothesis 2: Digital transformation of commercial banks indirectly promotes green innovation by alleviating corporate financing constraints.

(2) The mediating effect of corporate governance capacity

Stakeholder theory suggests that the success of an enterprise depends on whether it can effectively manage its relationship with multiple stakeholders, including not only shareholders, but also employees, communities, governments and other relevant subjects, and because the demands of different subjects may be both complementary and conflicting , corporate governance is no longer just between the board of directors and the management, but is a synergistic governance that spans across the enterprise, the society and the natural environment. Corporate ESG index is a comprehensive governance index that includes environmental impact, social responsibility, and governance structure, so ESG index is chosen to measure the comprehensive governance ability of enterprises.

A sound corporate governance structure binds management incentives to green projects, effectively inhibits the short-sighted behaviour of corporate managers, and encourages enterprises to invest in green projects with long cycles and high uncertainty; at the same time, higher ESG scores can

send a low-risk, high-value signal to the government and corporate investors, which is conducive to obtaining government subsidies, tax exemptions, and sufficient low-cost funds for green patent projects. From the business level, the digital platform of commercial banks transforms corporate governance information such as carbon emissions, patents and social responsibility from a manipulable disclosure mechanism to a verifiable and traceable data embodiment, and the digital transformation of commercial banks can improve the collection and processing efficiency of corporate ESG data through scientific and technological means, expand the scope and reach of financial services, simplify the intermediate process, and improve the efficiency of allocation. At the organisational management level, Wang Haijun et al. (2023) point out in their study that the improvement of data transparency significantly improves the transparency and visualisation of the management process, effectively mitigates the agency problem caused by information asymmetry, and pushes enterprises to improve their internal governance and strengthen their environmental responsibility, thus providing institutional incentives for green innovation, and prompting them to take the initiative to improve their environmental and social performance in order to enhance their ESG scores. Its strong data processing capabilities enable in-depth mining and accurate analysis of enterprise operating data, breaking down departmental barriers, enabling collaborative and intensive management, optimizing internal governance, and improving overall operational efficiency, thereby promoting higher corporate ESG levels. Better corporate governance strengthens recognition of green innovation's long-term value, cuts agency costs, boosts external legitimacy, activates green innovation motivation, expands access to green resources, and drives continuous leaps in enterprises' green tech innovation capabilities. Accordingly, we propose:

Hypothesis 3: The digital transformation of commercial banks indirectly promotes green innovation by improving corporate governance.

(3) The mediating effect of the level of financial marketisation

The level of financial marketisation determines factor price discovery and resource allocation efficiency, the higher the degree of financial marketisation, the more sensitive the factor prices are, and the more resources can flow to the most efficient areas. In their study, Hou Sheng and Wang Lang (2025) found that financial marketisation, with its low cost and high efficiency, can have a strong impact on other industries, promote cross-fertilisation between different industries, and create a good ecology for green innovation activities[14] . The digital transformation of commercial banks can expand the geographical boundaries of green financial services with the help of digital platforms, improve the degree of regional financial marketisation, and a higher degree of marketisation can reduce the cost of green project financing through competition and price mechanisms, and motivate enterprises to increase green innovation investment.

The accelerated pace of digital transformation of commercial banks has not only prompted more large banks to take the initiative to sink the centre of gravity of their services, but also enabled small and medium-sized banks to resolve their competitive disadvantages through scientific and technological means, and pushed the competitive landscape of the financial industry to diversify. The theory of competition deepening suggests that when the number of supplying entities increases, information barriers are lowered, and market pricing power is enhanced, it helps to improve the level of financial marketisation. At the enterprise level, it smooths savings-investment conversion, builds bank-enterprise info networks and optimizes capital allocation. At the government level, it reduces government-induced resource misallocation, refines interest rate reflection of green projects' risk-return and eases green innovation financing. At the social level, it boosts capital efficiency, deepens financial services, cuts costs and fosters a sound green innovation environment. It also notes that commercial banks' big data- and cloud computing-driven digital transformation enhances green credit, breaks barriers, intensifies competition, elevates regional financial marketization, enables precise credit direction to high-efficiency, low-carbon tech and shortens R&D-industrial application cycles, with improved resource allocation ultimately encouraging green innovation investment. The result is a direct incentive to invest in green innovation:

Hypothesis 4: The digital transformation of commercial banks indirectly promotes green innovation by increasing the degree of financial marketisation.

3. Research Design

3.1. Variable Selection and Descriptive Statistics

(1) Explanatory variables

Green Innovation (Green), green innovation is measured by taking the logarithm of the sum of the number of green inventions independently filed in the year and the number of green utility models independently filed in the year.

(2) Explanatory variables

Digital transformation of commercial banks (Fintech), derived from Digital Transformation Index of Chinese Commercial Banks released by Peking University, which constructs the index system from three dimensions of strategic digitalisation of commercial banks (Fintech1), business digitalisation (Fintech2) and management digitalisation (Fintech3) .

(3) Mediating Variables

In this paper, three intermediary variables are selected, namely, financing constraints, corporate governance capacity and the degree of marketisation as follows.

Financing constraints, financing constraints are measured by SA Index (Sahay-Aiyar Index) , proposed by Sahay and Aiyar, which is an exogenous financing constraint indicator based on the size and age of enterprises, and is widely used in the identification of mechanisms and grouping tests in the studies of green innovation, investment efficiency, credit allocation, etc.

Corporate governance capacity, corporate governance capacity is measured by ESG, ESG indicators (Environmental, Social and Governance Indicators) is a set of non-financial indicators used to measure the performance of enterprises in the three dimensions of Environment, Social and Corporate Governance.

The degree of financial marketisation (FMD), the degree of financial marketisation adopts the sub-dimension of the degree of development of the sub-index elemental market in the marketisation index compiled by Fan Gang et al.

(4) Control Variables

The control variables mainly include GrossProfit, NetProfit, Size, Inventory ratio (INV) and Accounts receivable ratio

(REC). Gross sales margin is measured by (Operating Revenue - Operating Costs)/Operating Revenue ; Net Sales Margin is measured by Net Profit/Operating Revenue ; Firm Size is measured by the natural logarithm of Total Assets; Inventory Ratio is measured by Net Inventory/Total Assets; and Accounts Receivable Ratio is measured by Net Accounts Receivable/Total Assets.

Table 1. Variable Definition Table

Variable Type	Variable Name	Variable Description
Explained Variables	Green	ln(number of green inventions independently filed in the current year + number of green utility models independently filed in the current year + 1)
Explanatory Variables	Fintech Fintech1 Fintech2 Fintech3	Digital Transformation Index of Chinese Commercial Banks published by Peking University
Intermediary Variables	SA	SA Index
	ESG	ESG Index
	FMD	FMD Index
Control Variables	GrossProfit	(Operating Revenue - Operating Costs)/Operating Revenue
	NetProfit	Net Profit/Revenue
	Size	Natural logarithm of total assets
	INV	Net Inventory/Total Assets
	REC	Net accounts receivable/total assets

3.2. Data Source

Green innovation (Green) from the National Intellectual Property Office (CNIPA), Commercial Bank Digital Transformation Index from the Digital Finance Research Centre of Peking University's "China Commercial Bank Digital Transformation Index Report", Enterprise Governance Capability (ESG) data from Wind ESG Rating Database, Financial Marketisation Degree (FMD) from the "China Marketisation Index Report", Financing constraints (SA), gross profit margin (GrossProfit), net profit margin (NetProfit), firm size (Size), inventory ratio (INV) and accounts receivable ratio (REC) can be obtained from CSMAR Financial Statements Library, so all the above data are available through public channels.

3.3. Model Construction

In order to study the relationship between digital transformation and green innovation in commercial banks, this study constructs the following fixed effects model:

$$Green_{i,t} = \alpha_0 + \beta_1 Fintech_{i,t} + \beta_2 control_{i,t} + \gamma_i + \mu_t + \epsilon_{i,t} \quad (1)$$

$Green_{i,t}$ denotes the level of green innovation, $Fintech_{i,t}$ is the explanatory variable for the level of digital transformation of commercial banks, $control_{i,t}$ denotes the control variable, γ_i and μ_t denote the individual and time fixed effects, respectively, and $\epsilon_{i,t}$ denotes the random error term, where i denotes the region and t denotes the year.

In order to deeply explore the role of commercial bank digital transformation on green innovation mechanism, this paper according to the construction of the mediation effect model to test, the model is as follows:

$$Med_{i,t} = \alpha_0 + \beta_1 Fintech_{i,t} + \beta_2 control_{i,t} + \gamma_i + \mu_t + \epsilon_{i,t} \quad (2)$$

$$Green_{i,t} = c_0 + c_1 Fintech_{i,t} + c_2 Med_{i,t} + c_3 control_{i,t} + \gamma_i + \mu_t + \epsilon_{i,t} \quad (3)$$

Where $Med_{i,t}$ denotes the mediating variables, which mainly include financing constraints (SA), corporate governance capacity (ESG) and financial marketisation degree (FMD). $Green_{i,t}$ denotes the level of green innovation, $Fintech_{i,t}$ is the explanatory variable for the level of digital transformation of commercial banks, $control_{i,t}$ denotes the control variable, γ_i and μ_t denote the individual and time fixed effects, respectively, and $\epsilon_{i,t}$ denotes the random error term, where i denotes the region and t denotes the year.

4. Empirical Analyses and Tests

4.1. Baseline Regression

Regression of equation (1), the regression results are shown in Table 2, the digital transformation of commercial banks has a significant positive impact on green innovation: whether it is the overall index or its three sub-dimensions of strategic digitisation, business digitisation and management digitisation, the coefficients are all significantly positive at the 1% level, indicating that the enhancement of the degree of bank digitisation can effectively promote the enterprise's

green innovation output, to verify the paper's hypothesis 1.

Table 2. Regression

	Green(1)	Green(2)	Green(3)	Green(4)
Fintech	0.041***			
	(0.016)			
Fintech1		0.024***		
		(0.009)		
Fintech2			0.036***	
			(0.013)	
Fintech3				0.057***
				(0.022)
GrossProfit	-0.107***	-0.107***	-0.107***	-0.107***
	(0.034)	(0.034)	(0.034)	(0.034)
NetProfit	0.067***	0.067***	0.067***	0.067***
	(0.018)	(0.018)	(0.018)	(0.018)
Size	0.049***	0.049***	0.049***	0.049***
	(0.006)	(0.006)	(0.006)	(0.006)
INV	0.086**	0.086**	0.086**	0.086**
	(0.040)	(0.040)	(0.040)	(0.040)
REC	0.171***	0.171***	0.171***	0.171***
	(5.141)	(5.141)	(5.141)	(5.141)
_cons	-85.048***	-85.128***	-85.127***	-84.921***
	(12.162)	(12.149)	(12.149)	(12.181)
id	YES	YES	YES	YES
year	YES	YES	YES	YES

Standard errors in parentheses $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$

4.2. Robustness Tests

(1) Tailoring

In order to verify that the conclusion that digital transformation of commercial banks can promote green innovation of enterprises is not driven by abnormal observations, all continuous variables are subjected to 1% two-sided tailing to eliminate extreme values. The results are shown in Column (1) of Table 3 below, the coefficients of the explanatory variable digital transformation of commercial banks still remain significantly positive, and the sign of the control variables and significance do not change, which indicates that the underlying regression conclusions are not disturbed by the abnormal values. interference.

Table 3. Robustness tests

	Tailoring(1)	Lagged explanatory variables(2)
	Green_w	Green
Fintech_w	0.036**	
	(0.015)	
L.Fintech		0.082***
		(0.011)
GrossProfit	-0.099***	-0.031
	(0.033)	(0.036)
NetProfit	0.062***	0.073***
	(0.017)	(0.019)
Size	0.047***	0.045***
	(0.006)	(0.006)
INV	0.080**	0.088**
	(0.039)	(0.044)
REC	0.173***	0.183***
	(0.050)	(0.056)
_cons	-0.809***	-0.738***
	(0.118)	(0.136)
id	YES	YES
year	YES	YES

Standard errors in parentheses $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$

(2) Lagged explanatory variables

The digital transformation of commercial banks is a dynamic process of change, the enhancement of green innovation ability of enterprises may be affected by the digital transformation of commercial banks in the previous period, this paper will take the value of the explanatory variables lagged one period for testing, the results are shown in column (2) of Table 3 below, the coefficient of which further increases

and maintains at the level of significance of 1%, which reflects that the impact of the digitalisation of commercial banks on green innovation has a continuous and dynamic cumulative effect.

4.3. Endogeneity Test

There may still be some unobservable omitted variables, while there may be reverse causation, this paper adopts the instrumental variable method to test the endogeneity problem that may be caused by omitted variables and reverse causation, among other reasons. The mobile phone penetration rate is used as an instrumental variable for the digital transformation of commercial banks, which does not directly affect the green innovation of enterprises and satisfies the exogeneity requirement, while the mobile phone penetration rate of the region where commercial banks are located is closely related to their digital transformation. The test results are shown in Table 4. Column (1) indicates the results of the first-stage regression, and it can be seen that the estimated coefficient of the instrumental variable Fintech_iv is significantly positive at the 1% level, indicating that the instrumental variable has a strong correlation with the digital transformation of commercial banks. Column (2) indicates that the estimated coefficient of digital transformation of commercial banks is significant at 1% level after removing the effect of endogeneity, which still has a facilitating effect on firms' green innovation capability. Meanwhile, the K-P W F statistic of 2789.37 and the K-P LM statistic of 1853.904 reject the original hypothesis of weak instruments and insufficient identification of variable instrumental variables.

Table 4. Endogeneity test

	(1)	(2)
	first	second
VARIABLES	Fintech	GreenInnovation
Fintech_iv	0.946***	
	(0.045)	
Fintech		0.255***
		(0.080)
GrossProfit	0.165***	-0.450***
	(0.028)	(0.114)
NetProfit	-0.300***	0.313***
	(0.017)	(0.076)
Size	0.0485***	0.189***
	(0.0046)	(0.022)
INV	-0.442***	-0.948***
	(0.036)	(0.154)
REC	0.274***	0.345***
	(0.047)	(0.025)
K-P W F statistic	2789.37	
K-P LM statistic	1853.904***	
id	YES	YES
year	YES	YES

Standard errors in parentheses $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$

4.4. Test of Mediating Mechanism of Commercial Banks' Digital Transformation on Green Innovation

(1) Alleviation of financing constraints

The mediating effect of financing constraints is shown in Table 5 Column (2) shows that the estimated coefficient of the explanatory variable commercial bank digital transformation index on financing constraints is significantly negative, indicating that the higher the level of digitalisation of commercial banks, the more significant the alleviation of financing constraints. Meanwhile, column (3) shows the results of the simultaneous regression of commercial bank digital transformation and financing constraints, and the results show that they are significant at the 1% and 5% levels, respectively. In summary, it can be seen that the mediation mechanism is established, which means that the digital transformation of commercial banks, with the help of big data and algorithms, can reduce the cost of financing and expand the amount of financing, and the alleviation of financing constraints provides enterprises with a stable cash flow and long-term funding. The results in Column (2) and Column (3) together verify that the digital transformation of commercial banks can enhance the transmission path of green innovation by alleviating the financing constraints, validating Hypothesis 2 of this paper.

(2) Corporate governance capacity

According to Table 5, Column (4) and Column (5) show the results of the mediation effect test of corporate governance capacity, in which the coefficient of commercial bank digital transformation on corporate governance capacity in Column (4) is significantly positive at the 1% level, indicating that the digital transformation of commercial banks can effectively improve corporate governance capacity. Column (5) shows the results of the simultaneous regression of commercial banks' digital transformation and corporate governance capacity, and the results show that the coefficient of commercial banks' digital transformation on corporate governance capacity is significantly positive at the 5% and 1% levels, respectively. It indicates that the digital transformation of commercial banks can rely on the powerful data processing capacity of digital technology, which can carry out in-depth excavation and accurate analysis of enterprise operation data, and then break departmental barriers to achieve collaborative operation and intensive management within the organisation. By mining real-time data and sharing dashboards, digital banks dismantle silos, cut information asymmetry and tighten governance, sparking firms' green-innovation drive and resource-pulling power in a self-reinforcing loop. The results of column (4) and column (5) together verify that the digital transformation of commercial banks can promote the enhancement of green innovation ability of enterprises

through the channel of improving corporate governance ability, which verifies the hypothesis 3 of this paper.

(3) Degree of financial marketisation

From Table 5, Column (6) and Column (7) are the results of the mediation effect test of the degree of financial marketisation, in which the estimated coefficient of the digital transformation of commercial banks on the index of the degree of financial marketisation in Column (6) is significantly positive at the 1% level, indicating that the digitalisation of commercial banks can significantly improve the degree of financial marketisation. Column (7) found that the coefficient of the degree of financial marketisation is significantly negative after adding the mediating effect financial marketisation degree, the coefficient of the explanatory variable rises from 0.041 to 0.080, the mediating path and the direct path act in partly opposite directions, and there is a masking effect, the mediating effect and the direct effect are of opposite signs, and the absolute value of the mediating effect is greater than that of the total effect, which is reflected in the fact that the digital transformation of commercial banks. By promoting the degree of financial marketisation indirectly weakened its own direct positive impact on green innovation, and ultimately the digital transformation of commercial banks has a predominantly direct positive impact on green innovation, while being moderated by the masking of the mediating variables, which is contrary to the hypothesis of this paper4 . The reason may be that commercial banks' digital transformation uses data to quickly identify potential green innovation enterprises, driving more financial resources into the market and accelerating financial marketization. Yet higher financial marketization intensifies competition, enterprises tend to invest in short-term, low-risk, high-return projects instead of green innovation projects, reducing green innovation investment intensity.

Table 5. Intermediary mechanism test

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Green	SA	Green	ESG	Green	FMD	Green
Fintech	0.041***	-0.005***	0.017***	0.002***	0.037**	0.023***	0.080***
	(0.016)	(0.000)	(0.005)	(0.000)	(0.016)	(0.000)	(0.000)
SA			-0.141**				
			(0.058)				
ESG					0.019***		
					(0.003)		
FMD							-0.038***
							(0.005)
GrossProfit	-0.107***	-0.035***	-0.272***	0.138**	-0.110***	-0.605***	-0.084**
	(0.034)	(0.004)	(0.104)	(0.059)	(0.033)	(0.033)	(0.033)
NetProfit	0.067***	0.024***	0.137**	0.263***	0.062***	0.041**	0.071***
	(0.018)	(0.002)	(0.055)	(0.031)	(0.018)	(0.018)	(0.018)
Size	0.049***	-0.010***	0.117***	0.190***	0.045***	-0.005	0.050***
	(0.006)	(0.001)	(0.018)	(0.010)	(0.006)	(0.006)	(0.006)
INV	0.086**	-0.048***	0.289**	0.339***	0.079**	0.181***	0.099**
	(0.040)	(0.005)	(0.126)	(0.072)	(0.040)	(0.041)	(0.041)
REC	0.171***	-0.037***	0.640***	0.127	0.169***	-0.285***	0.185***
	(0.051)	(0.006)	(0.160)	(0.091)	(0.051)	(0.052)	(0.051)
_cons	-0.850***	-3.190***	-1.252***	-0.373***	-0.844***	8.255***	-0.548***
	(0.122)	(0.015)	(0.144)	(0.140)	(0.122)	(0.122)	(0.128)
id	YES	YES	YES	YES	YES	YES	YES
year	YES	YES	YES	YES	YES	YES	YES

Standard errors in parentheses $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$

4.5. Heterogeneity Analysis

In order to verify the ability of commercial banks' digital transformation to influence green innovation in different regions, the sample is divided into three groups based on provinces: eastern, central and western, and the base regression is re-run for each region. According to the subregional regression results shown in Table 6, the estimated coefficient of commercial bank digital transformation in the eastern region is significant at the 1% level, the estimated coefficient in the central region is significant at the 5% level, and it is not significant in the western region, and the facilitating effect of digital transformation of commercial banks shows the strongest tendency in the east, followed by

the central region, and the weakest tendency in the west. The reason for this heterogeneity is that in the east, the east's solid digital rails, deep finance and capable firms let bank digitisation turbo-charge green innovation; the centre gains modestly, while the west's patchy infrastructure, high capital costs and weak absorptive capacity trap its firms outside the digital dividend, carving a clear east-to-west downward gradient.

Table 6. Regional Heterogeneity

	East	Central	West
	Green	Green	Green
Fintech	0.050***	0.033**	-0.003
	(0.009)	(0.016)	(0.016)
GrossProfit	0.076***	-0.192***	-0.240***
	(0.029)	(0.057)	(0.052)
NetProfit	0.081***	0.233***	0.078
	(0.027)	(0.058)	(0.048)
Size	0.134***	0.137***	0.131***
	(0.004)	(0.008)	(0.007)
INV	-0.404***	-0.013	-0.246***
	(0.036)	(0.081)	(0.071)
REC	1.205***	1.619***	0.802***
	(0.046)	(0.094)	(0.085)
_cons	-2.954***	-2.964***	-2.615***
	(0.086)	(0.175)	(0.162)
id	YES	YES	YES
year	YES	YES	YES

Standard errors in parentheses $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$

5. Conclusion of the Study and Policy Recommendations

5.1. Research Conclusion

This paper examines the impact of commercial banks' digital transformation on green innovation, and through reading and analysing relevant literature, it is found that under the intersection of the "dual-carbon" goal and the digital China strategy, commercial banks' digital transformation has become a key factor in driving green innovation. The findings of this paper are as follows: (1) through regression, it can be seen that the digital transformation of commercial banks can significantly enhance the green innovation capability of enterprises, and the findings are robust; (2) in the path study, it is found that the digital transformation of commercial banks can systematically stimulate the green capability of enterprises by reducing information costs, strengthening risk control and optimising resource allocation, and then easing the constraints of corporate finance and enhancing the performance of corporate ESG. ability, while there is a masking effect in the degree of financial marketisation, when the degree of financial marketisation is increased, market competition intensifies, and financial institutions, under the profit-seeking motive, are more inclined to invest resources in projects with high short-term returns and lower risks, and green innovation is characterised by long-term and high risks, thus inhibiting green innovation of enterprises; (3) the part of the analysis of heterogeneity mainly focuses on regions. The regional heterogeneity shows that the promotion effect of digital transformation of commercial banks on green innovation shows the difference of strong in the east, second in the centre and weaker in the west.

5.2. Policy Recommendations

Through the above theoretical analysis and empirical findings of commercial banks' digital transformation on green innovation, this paper puts forward the following policy recommendations from the three dimensions of enterprises, banks and government:

From the enterprise level, state-owned enterprises should give full play to their scale and governance advantages, build enterprise-level industrial internet platforms, and take the lead in building upstream and downstream green supply chain collaboration networks; non-state-owned enterprises need to strengthen the top-level design of their digital strategies, and make up for the shortcomings of green processes and ESG disclosure by leveraging industry-academia-research cooperation among colleges, universities and scientific research institutions.

From the bank level, state-owned banks should take advantage of capital and technology spillover to share mature risk control models and green credit algorithms with small and medium-sized banks to promote synergistic development of large and medium-sized banks; joint-stock and rural commercial banks should enhance their ability to accurately serve SMEs in green innovation; and urban commercial banks should lower the threshold of scientific and technological investment by sharing data.

From the government level, the government should establish a cross-regional digital financial public service system, improve the sharing platform of carbon emission, ESG and patent data, reduce the asymmetry of information between banks and enterprises, and provide financial subsidy

loans for green innovation enterprises to reduce the repayment pressure on enterprises. Regulators should implement differentiated supervision, incorporate the proportion of banks' digital green credit into the macro-prudential assessment, and at the same time relax the access to innovative applications such as artificial intelligence and blockchain, strengthen data security and privacy protection, and build a dynamic risk early warning system.

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