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Aligning Local Power with Financial Innovation: Environmental Decentralization, Digital Finance, and the Rise of Green Technologies

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Abstract

This study highlights the crucial role of financial development in promoting green technology innovation, while noting the limitations of traditional financial institutions. It finds that digital finance is an effective tool for stimulating environmentally friendly innovation in China. Using panel data on firms and cities, the results show that digital finance significantly enhances green technology development by easing financial constraints, improving firm structures, and encouraging technological breakthroughs. These effects are especially strong for small firms and in highly polluted regions with strong sustainability initiatives and developed financial systems. The study also demonstrates that environmental decentralization strengthens the positive impact of digital finance on green innovation and recommends greater adoption of digital tools by financial institutions alongside institutional and governmental reforms to support sustainable innovation.

Keyword
Environmental Decentralization, Digital Finance, Green Technology Innovation, Local Governance, Financial Inclusion, Sustainable

ملخص

تُبرز هذه الدراسة الدور المحوري للتنمية المالية في تعزيز الابتكار في التقنيات الخضراء، مع الإشارة إلى القيود التي تواجهها المؤسسات المالية التقليدية في هذا المجال. وتُظهر النتائج أن التمويل الرقمي يُعد أداة فعّالة لدعم الابتكار البيئي في الصين. وبالاعتماد على بيانات لوحية تشمل الشركات والمدن، توضح الدراسة أن التمويل الرقمي يساهم بشكل كبير في تطوير التقنيات الصديقة للبيئة من خلال تخفيف القيود المالية، وتحسين هياكل الشركات، وتعزيز التقدّم التكنولوجي. وتكون هذه الآثار أكثر وضوحًا لدى الشركات الصغيرة وفي المناطق ذات مستويات التلوث المرتفعة والأنظمة المالية والمؤسسية المتطورة. كما تشير الدراسة إلى أن اللامركزية البيئية تعزز التأثير الإيجابي للتمويل الرقمي على الابتكار الأخضر، وتوصي بتوسيع اعتماد الأدوات الرقمية في القطاع المصرفي، إلى جانب إصلاحات مؤسسية ودعم حكومي أقوى لتعزيز الابتكار المستدام.

الكلمات المفتاحية:
اللامركزية البيئية، التمويل الرقمي، الابتكار في التكنولوجيا الخضراء، الحوكمة المحلية، الشمول المالي، الاستدامة.

1.Introdcation

Environmental pollution poses a significant challenge to the sustainability of the globe in the state it is today. Economic globalization has facilitated global commerce and investment, but it has also led to the depletion of resources and the decentralization of environmental issues (Pan et al. 2022). Consider China, a rapidly developing country whose impressive economic expansion has been accompanied by the deterioration of its natural surroundings (Dang and Wang 2022). Novel eco-friendly technology provides optimism for enterprises to optimize resource use and minimize pollution (Wang, Rani, and Razzaq 2023). Securing funding for intricate technologies might pose challenges owing to their substantial initial expenses and extended repayment periods (Q. Zhang, Chen, and Feng 2021).Conventional financiers need help fulfilling the financial requirements for advancements in environmentally friendly technologies. (Anderson 2001) discovered that individuals who engage in this behaviour tend to favour giant corporations, prioritizing profit above ecological concerns, while disregarding smaller enterprises, prioritizing social and economic responsibility. Prior financial constraints also curtail the ability to invest in environmentally conscious enterprises and their goods, including green technologies in conventional production (Zhou et al. 2023).

Digital currency offers a novel perspective on overcoming these limitations. By integrating digital technology with economic services, digital finance innovations can alleviate financing constraints (X. Li et al. 2022). Advances in digital technology, such as the Internet of Things and the availability of large amounts of data, have led to many digital financial services, including digital finance, online investing, and mobile payment techniques. This research examines the capacity of digital finance to stimulate advancements in eco-friendly technology. This study analyzes the influence of digital funding on the development of eco-friendly technologies and explores the possible involvement of government action. This investigation provides several significant additions: This study analyzes digital technology's influence on green innovation funding. Isolating digital technology's impacts on the banking industry contributes to our comprehension of financing constraint theory. It examines the influence of digital finance on advancements in green technology from various angles. Analyzing financial limitations, technological progress, and engineered creativity provides a more comprehensive understanding of the connection.

Consider the potential of environmental decentralization to enhance digital finance's beneficial impact on the development of green technology. It is essential to foster advancement in a decentralized ecological system. Our research aims to have a substantial effect on the area of green technology innovation and the variables that influence

its financial support by addressing these crucial topics. There have been notable changes in China's digital financial industry in recent years. The data materials market, with an estimated value of 81.5 billion yuan in 2021, is expected to see a compound annual growth rate (CAGR) of more than 25% over the "14th Five-Year Plan" period (2021-2025). The significant increase in value results from the widespread use of digital technology in the many interconnected distribution networks in the financial sector, which include assets, persons, companies, and innovations. The main focus of prior research: Within the field of digital finance research, surfaced: The first level is dedicated to theoretical matters. This topic delves into the ideas, origins, and features of digital technology used in the financial industry. (Cao et al. 2021) and (Lin and Ma 2022) together investigate the possible legislative and administrative deficiency that might emerge from the integration of digital technology, along with its anticipated financial worth. Researchers have also investigated the concept of the "Jevons Paradox" paradigm (Fan et al. 2023), which suggests that people may spend more and produce additional greenhouse gases due to the convenience of digital data.

The research in this field focuses on the practical outcomes of technical advancements in digital finance on financial decision-making. Various studies have investigated the impact of the "Belt and Road Initiative" on different areas. These include its effects on creativity in urban areas, consumer behaviour, export trade, greenhouse gas emissions reduction, environmental quality, industrial facility improvements, neighbourhood economics, and environmental sustainability. The studies referenced are conducted by (W. Chen et al. 2020), and (D. Li et al. 2017), (Feng, Zhang, and Li 2022), (Y. Zhang and Li 2022), (Song, Du, and Tan 2018), (A. Asongu and Nwachukwu 2018), (Habib, Abbas, and Noman 2019), (Asongu and Odhiambo 2018), (Jin, Gao, and Pan 2023), (H. Chen et al. 2023). This research investigates how advanced technology in finance overcomes the challenges faced by traditional financial services.

2. Literature reviews

The advancement of green technology drastically facilitates the development of sustainable growth in economies(H. Chen et al. 2023) found that it enhances resource use and hampers greenhouse gas emissions from pollutants in their production process. However, funding technical advancements of this nature may pose challenges due to their intricate nature, substantial initial expenses, and lengthy return periods ((Wang, Rani, and Razzaq 2023); (Chishti and Sinha 2022). (Asongu and Odhiambo 2018) and (G. Li, Guo, and Di 2021)have found that traditional financing sources frequently need help to fulfil these funding expectations due to their preference for established enterprises with lower risks. This literature review investigates the potential impact of digital finance on promoting innovation in environmentally friendly technology. This text examines the research about the factors that promote innovation in

green technology, the limitations of traditional banks, and how digital finance can address these challenges. Moreover, it explores the influence of environmental decentralization on the relationship between digital currencies and advancements in sustainable technologies.

Factors that Influence the Advancement of Environmentally Sustainable Technologies.

At the business level, the progress of green technology is influenced by various factors. According to (Anderson 2001), (Hajer et al. 2015),(Syed and Bouri 2022), a comprehension base, technological competency, and an organizational perspective are identified as three critical factors. Studies have indicated that companies with strong technical capabilities and extensive knowledge bases are more likely to implement innovative, environmentally friendly technology successfully (Udeagha and Ngepah 2022). The research on green supply chain management techniques in China indicates that adopting a green economic approach encourages the development of collaborative innovations with both suppliers and customers, as stated by (X. Li et al. 2022). Additionally, there are significant external factors to take into account. Businesses are incentivized to engage in green innovation projects because of the ever-changing market and increasing demand for eco-friendly products, as stated by (Jiang and Deng 2022). Imposing restrictions on pollutants can operate as a market deterrent by increasing the financial burden on enterprises for their emissions, motivating them to develop methods to produce cleaner products (Škare, Gavurova, and Porada-Rochon 2024). However, regulations can have intricate consequences. The Porter Hypothesis suggests that companies are likely more driven to innovate when faced with rigorous legislative requirements (Hajer et al. 2015). Conversely, some individuals express concern that limitations might exacerbate the financial burden on already scarce funds for research and development (Dzwigol et al. 2024).

The inclusion of environmental decentralization, wherein federal and state governments collaborate to oversee the Earth's resources, introduces additional complexity (Wang, Rani, and Razzaq 2023). If given greater control over local environmental management, enterprises may be more motivated to adopt environmentally friendly practices (Udeagha and Ngepah 2022). However, in the short term, local authorities may prioritize economic development over environmental preservation, thus reducing enterprises' motivation to innovate to reduce emissions. Due to several factors, traditional financial organizations sometimes need to provide more funding for developments in green technology. Conventional lenders, who are cautious about taking risks, are not attracted to green technology innovation ventures since they require high upfront costs and have long periods before generating returns (Wang, Rani, and Razzaq 2023). Conventional banks may need more expertise to assess the value of green technology

initiatives, as they often fail to consider the social and environmental implications associated with such projects (Liu and Wang 2023). This could result in a need for more funding for promising environmentally friendly inventions.

Digital banking holds promise for eco-friendly technical improvements due to various factors. According (Suhrab, Chen, and Ullah 2024) and (Lin and Ma 2022), digital finance can enhance the accessibility and effectiveness of financial services by reducing transaction costs and knowledge imbalance. Consequently, green technology firms may discover more readily available and cost-effective finance opportunities. Furthermore, a more significant number of individuals can participate in promoting environmentally friendly technology initiatives through the utilization of digital financial platforms that facilitate peer-to-peer lending and crowdfunding (Saeed Atobishi Thabit Hegedűs 2023).

Green technology innovation may secure the necessary capital using digital finance, which offers several improvements over traditional banking. This paper explores how digital finance can solve these challenges and enhance the social framework for sustainable innovation. Minimizing interaction costs and improving communication An inequality: The reliance of traditional financial organizations on infrastructure and outdated processes sometimes leads to many expenses for both borrowers and lenders. On the other hand, digital banking employs data analysis and robots to streamline operations, significantly reducing transaction costs (Banna and Alam 2021). Bankers are more inclined to support emerging green technology companies when lower capital amounts are possible. The credit assessment process has become more transparent and effective due to technology technologies that gather and analyze large amounts of data. To address the challenge of knowledge asymmetries faced by green technology enterprises, implementing green technological initiatives can be helpful due to their distinctiveness and intricacy (Alexey Kudryavtseva Svetlana Samarina 2023). Digital finance may mitigate risk aversion and enhance investment by providing lenders with comprehensive data on the potential of green technology ventures.

Financing and Economic Engagement: Startups or entities in non-central economic hubs may encounter challenges in attracting curiosity and securing the necessary backing from traditional financial institutions. Green technology enterprises are just one of the many potential borrowers that digital finance platforms might target because of their internet accessibility and inherent scalability (Banna and Alam 2021). Integrating green technology companies into the established financial system and providing them with funding opportunities is an effective strategy to advance financial inclusion. Philanthropy and peer-to-peer borrowing are two instances of alternative financial structures that have the potential to thrive on digital platforms. (X. Li et al. 2022) have conducted studies showing that these platforms

allow a broader range of investors, including those strongly dedicated to pushing for environmental responsibility, to participate in financing green technology projects. By implementing this approach, we may effectively address the financial shortfall numerous green innovation initiatives face and access a new reservoir of funds.

In digital banking, computer intelligence, commonly called AI, is utilized along with vast quantities of data to develop sophisticated algorithms for risk analysis. This enables the creation of new financial services and information-driven risk assessment methods. By integrating traditional financial indicators with these models, a more comprehensive understanding of green technology projects' social and ecological impacts can be obtained (McKay et al. 2022)The financing terms for green technology businesses could be enhanced due to an enhanced understanding of the risks and advantages associated with these endeavours. In addition, digital finance is being utilized to provide innovative financial solutions tailored to the specific needs of green technology enterprises. Environmental securities, sustainability-linked finance, and impact investments are financial tools that can allocate funds specifically to support environmentally friendly projects (Udeagha and Ngepah 2022).

Entrepreneurs focused on sustainable and environmentally friendly technology projects can effectively find financial support through digital channels. (Youssef and Dahmani 2024) elucidates that these platforms employ data-driven data analysis and machine learning techniques to facilitate the connection between financiers and projects that align with their ethical and environmental principles. In order to address the financial shortfall, this targeted approach could attract a cohort of investors previously actively involved in environmentally friendly innovation. Decentralization in the Environment and the Implementation of Digital Finances:

As mentioned earlier, green technology innovation encounters a complex landscape due to environmental decentralization. While granting greater local control may promote the implementation of increased environmental standards and foster green innovation, it can also lead to the relaxation of limitations in some instances (Jiachao Fu Shuke Gao 2023). Digital finance may play a significant role in streamlining this process. Expanding access to financial services and opening up new avenues for finance may benefit green tech enterprises operating in regions with less stringent environmental regulations. Even without comprehensive local regulations, digital finance can incentivize enterprises to adopt less environmentally harmful technology and contribute to environmental goals by increasing their access to financial backing.

3. The Theoretical Evaluation and Elaboration of Investigation Proposals

The traditional financial sector, which often relies on physical branch spots, is limited by constraints that digital monetary services abolish. Green technology firms can acquire money via digital finance, which utilizes smartphones and tablets to navigate places with little recourse to traditional banking (A. Asongu and Nwachukwu 2018). Increased awareness among individuals will enhance the likelihood of making communal funds available for green innovation ventures.

Digital finance offers a broader array of financing choices than traditional financial organizations. Green technology enterprises possess distinct financing needs, which are fulfilled via consumer and supplier network finance. Technology facilitates crowdsourced and P2P financing, making green venture capital accessible to a broader range of financiers, such as those motivated by environmental goals (Wei et al. 2023).

Reducing disparities in knowledge and optimizing the allocation of resources:The extensive level of intricacy and distinctiveness of green technology projects makes it challenging for conventional finance institutions to accurately evaluate their future prospects. (Aleksy Lyulyov Oleksii Pimonenko 2023) have shown that green technology firms have challenges securing financial resources because of a lack of shared understanding.

Conversely, digital finance utilizes artificial intelligence and vast data to develop ever-intricate models for assessing threats. (Saeed Atobishi Thabit Hegedűs 2023) argue that these approaches offer an additional thorough evaluation of green technology efforts by integrating traditional financial metrics with data on their environmental and societal impacts. This comprehensive approach may provide a more thorough understanding of the risks and advantages associated with these projects, hence reducing information discrepancies. As a result, bankers have a more significant incline to provide favourable terms to green technology businesses when providing funding.

Promoting Sustainable Manufacturing and Technological Advancement in the Commercial Sector:

Digital finance facilitates the development of green technology by simplifying the updating of production operations. In order to accomplish that, it utilizes:

Digital finance facilitates the growth of rapidly expanding enterprises, particularly those in technical and emerging areas, by decreasing the expenditures and obstacles associated with obtaining financial assistance. This fosters innovation and pushes the technology sector towards more environmentally sustainable alternatives.

(Salam 2024) assert that monetary systems may use extensive data and cloud-based technologies to eliminate unproductive firms efficiently and reallocate capital to industries with more promise for innovation in green

technology. Through this process of optimization, there is a decrease in energy usage, which promotes the restructuring of industries.

Merging data from consumers and suppliers, digital finance enhances the financial networks of corporate distribution (Hajer et al. 2015). This fosters collaboration and facilitates the use of eco-friendly technologies by enterprises in the manufacturing sector.

Hypotheses in progress:

Based on the provided framework, we formulate many study hypotheses.

Hypothesis 1: The advancement of digital financial systems may substantially contribute to developing environmentally friendly technologies.

Hypothesis 2A: The advancement of digital financial systems may enhance the growth of green technology innovation in a specific area by reducing the fiscal constraints faced by enterprises.

Hypothesis 2B: The advancement of digital financial development may enhance localized green technology innovation by facilitating the renovation of the economic system.

Hypothesis 2C: The advancement of digital financial services may enhance the progress of green technology innovation locally by facilitating the growth in production activities.

Environmental decentralization refers to transferring authority and decision-making power from central government bodies to local or regional entities in matters related to the natural world. This decentralization enhances local participation and accountability in environmental management and governance. Decentralization gives towns and cities the power to manage the environment. This may impact the efficacy of digital funding in fostering advancements in eco-friendly technology. Due to stricter regulations, firms with vital sustainability goals in a region may compete to improve their technology and adopt cleaner practices. Based on research conducted by (Salam 2024) and (Hakanen and Rajala 2018), there is a growing need for local businesses to adopt new environmentally friendly technology. Digital finance has the potential to significantly impact these firms by providing the necessary cash for the implementation of environmentally friendly solutions.

Environmental decentralization facilitates online financing by state and municipal agencies to stimulate green innovation among suppliers.

Reducing Collaboration Asymmetry: Digital finance facilitates improved communication between municipal agencies and green technology entrepreneurs, leading to more equitable allocation of national funding for innovation and enhanced identification of viable businesses.

The amalgamation of decentralization and digital finance has the potential to bridge the information disparity between financial organizations and green technology enterprises, hence facilitating funding from entrepreneurs. (Sartal et al. 2020) and (Dzwigol et al. 2024) have shown that this enhances the economic stability of environmentally friendly innovation projects and creates opportunities for obtaining more financing.

Therefore, we have the following hypothesis.

Hypothesis 3: Environmental decentralization facilitates the advancement of digital finance to bolster invention in green technologies.

4. Data and Methods

4.a. Description for variables

Dependent Variable: Green Technology Innovation (GTI)

The article explores the correlation between developing green technology innovation and using digital financial services. Green technology innovation, often known as "eco-innovation" or "environmental innovation," refers to the development of new technologies that positively impact the state of the earth. Potential implications of these developments include enhanced consumption of materials from biological terms, reduced emissions, and increased resilience against ecological hazards. This study utilizes the amount of energy model submissions and localized green technology licenses for inventiveness to gauge the level of green technology advancement in each location. A greater variety of applications enhances the potential of a region to develop green technology.

Intellectual ownership data offers several advantages for tracking the evolution of green technology. Patents manifest the outcomes of companies' endeavours to develop environmentally friendly technology. Furthermore, investigators can discern which patents are relevant to environmentally friendly advancements and which are usually otherwise since inventions are categorized based on their technological classification. Furthermore, the International Patent Classification (IPC) offers a system for identifying and acknowledging advancements in environmentally friendly

technology. The green technology categories listed in the OECD's "Compare and of Technological Domains and IPC Classification List," which this research utilizes, include technologies that decrease energy use, water usage, and pollution.

Obtaining trademark data for every city at the district level may take time. Therefore, this research relies on data obtained at the provincial level. However, in certain localities within each area, relying just on the sheer number of inquiries might be deceptive. The research used a min-max normalization strategy to address this problem and ensure that the data is similar across different places. This algorithm transforms empirical information on patents by province into a relative index that ranges from zero to one. This approach enables a more precise comparison of the potential of different locations for green technology innovation by converting numerical data into proportional indicators, therefore eliminating the influence of size. Finally, to assess the advancement in green technology within every municipality, standardized data from provinces is compared with data from localities at the metropolitan level. This approach may be used to get a more comprehensive assessment of the innovation of green technology occurring in various places.

Independent Variable: Digital Finance (DF)

The research examines the influence of digital finance on the advancement of green technology innovation. This research used "The Peking University Digital Financial Inclusion Index of China" as a proxy to measure the autonomous digital finance (DF) variable. This index, formulated using data supplied by Ant Financial, measures three fundamental elements of digital financial advancement in different locations in China:

Dimensions of Application: This aspect measures how digital investments are easily accessible in a particular location. It considers variables such as the number of digital financial service firms and the extent of respective geographical coverage of assistance.

Utilization Level: This metric assesses the severity with which people and organizations in a certain area use financial technology. Relevant variables include the quantity of operations and the diversity of digital financial instruments used.

Digital transformation Level: This dimension pertains to the technical advancement of the digital economy in a particular area. It includes elements such as the implementation of cutting-edge technology (such as big data and the Internet of Things) and the general development of the digital economic environment.

By utilizing this extensive index, the study circumvents the need to depend on a solitary metric and acquires a more thorough comprehension of digital financial growth throughout various places. The median level of the indicator saw a substantial rise from 46.9 to 216.38 between 2010 and 2018, indicating a solid growth rate of 29.03% per year. This data underscores the swift spread of digital financial services in China through that time time frame.

Control variables

The present analysis incorporates many control factors to account for external effects that could affect a location's capacity to create green technology, in line with previous studies by (Jiachao Fu Shuke Gao 2023) and (Weiran Cai Zengjie Yao 2023). Here are some of the factors: Human Capital (HC) refers to the share of GDP that goes toward education. Investing in educational institutions enhances the region's ability to develop green technology.

To determine what percentage of GDP goes toward government transfer payments **(GTR)**, we look at information from each province instead of data from individual cities. The size of government transfer payments, particularly those for environmental protection, may affect green technology innovation. One measure of economic growth is the gross domestic product (GDP) relative to the country's population. Most people think governments at higher socioeconomic levels would support green technology innovation projects more strongly. One measure of regulatory effectiveness **(ER)** is the proportion of GDP that goes toward pollution prevention efforts. Environmental restrictions will have a positive effect on green technology innovation.

• Other Control Variables: The research includes decentralization of the environment **(EC)**, fiscal constraints **(FC)**, industrial structure upgrade (**ISR)**, and manufacturing development (MD). Table 1 provides further explanation and data sources for these variables.

Table 1. Characterization and origins of variables.

Variables	**Initials**	**Description**	**Measurement**
Innovation in green technology	GTI	Any specific type of innovation that leads to or intends to make substantial and provable advancements towards equitable growth by decreasing the adverse effects on the environment,	Estimated amount of trademarks for inventions and applications related to green technology.

Variables	Initials	Description	Measurement
		improving the ability to withstand climate change, or attaining a more effective and environmentally conscious use of natural assets.	
Digital Finance	NDF	The emerging trend involves lenders and digital firms using digital technology to finance, make payments, and provide investment solutions.	Digital Financial Inclusion Index
Human Capital	HC	Local investment in educations	Education expenditure (% GDP)
Governments (Transfer payments)	GTR	The central government transfers some financial resources to local governments	The ratio of federal payments for transfers to regional financial income.
Economic Development	ED	Enforcement of regulations targeting different activities that cause pollution to save the environment.	Enforcement of regulations targeting different activities that cause pollution to save the environment.
Environmental Regulation	ERT	Enforcement of regulations targeting different activities that cause pollution to save the environment.	Percentage of GDP allocated to investment in environmental pollution prevention.
Environmental Decentralization	EC	Allocation of environmental management jurisdiction between the central and local governments signifies a shift in responsibility for safeguarding the environment from the national government to the regional authorities.	Total count of investments central and local governments make in environmental pollution control.
fiscal Limitation	FL	Limitations on investment by companies arise when there is a disparity in the expenses associated with both internal and external funding	KZ and SA index

Variables	Initials	Description	Measurement
Industrial Structure Upgrading	ISU	Optimizing the distribution and effective use of resources across industries using technology advancements to drive significant enhancements in the quality of the industrial framework and overall degree of growth	Level of rationalization in the industrial system.
Quality of Manufacturing Development	QMD	The magnitude and calibre of industrial advancement	The ratio of the value produced contributed to the total value generated across all sectors

4.2. Empirical models

Experimental evidence indicates the possibility of a linear correlation between digital finance and invention in green technology. We use a two-sided fixed-effects model to investigate the marginal impact of digital finance.

(1)

$$\begin{aligned} \ln GTI_{it} = {} & \alpha_0 + \alpha_1 \ln NDF_{it} + \alpha_2 RD_{it} + \alpha_3 GFE_{it} + \alpha_4 GI_{it} \\ & + \alpha_5 \ln GDP_{it} + \alpha_6 ERT_{it} + \alpha_6 EC_{it} + \mu_t + \theta_i + \epsilon_{it} \end{aligned}$$

The variables in the equation are defined as follows: $\alpha 0$ represents the intercept, $\alpha 1$ - $\alpha 7$ represent the regression coefficients for the variables, θi represents the regional fixed effect, μt represents the temporal fixed effect, and ϵit represents the chance error. The variable "i" represents the geographical dimension, whereas the variable "t" represents the aspect of time.

Moreover, we examine the three processes by which digital finance contributes: alleviating financing limitations, facilitating industrial structure upgrading and manufacture developing. The models are defined as follows:

$$lnGTI_{it} = \beta_1 + \beta_2 lnNDF_{it} + \theta_i + \mu_t + \epsilon_{it} + \sigma Control \quad (2)$$

$$INT_{it} = \varphi_1 + \varphi_2 lnNDF_{it} + \theta_i + \mu_t + \epsilon_{it} + \sigma Control \quad (3)$$

$$lnGTI_{it} = \tau_1 + \tau_2 lnNDF_{it} + \tau_3 INT_{it} + + \theta_i + \mu_t + \epsilon_{it} + \sigma Control \quad (4)$$

β_1 , φ_1 and τ_1 represents the intercept, $\beta_2, \varphi_2, \tau_1, \tau_2, \tau_3$ and σ represent the regression coefficients for the variables . The variable INT represents the mediating variables, which consist of finance limitations (FL), industrial structure upgrading (ISR), and manufacturing development (MD). The collection of control variables is denoted as control. Environmental decentralization is considered a threshold variable, and a threshold regression model is expressed as follows:

$$\begin{aligned} lnGTN_{it} = {} & \alpha_1 + \delta_2 lnNDF_{it} \cdot I(EC_{it} < \gamma_0) \\ & + \delta_3 lnNDF_{it} \cdot I(\gamma_1 \le EC_{it} < \gamma_1) \\ & + \cdots + \delta_n lnNDF_{it} \cdot I(EC_{it} > \gamma_n + Control + \epsilon_{it} \end{aligned} \quad (5)$$

The threshold value is denoted as , while the number of thresholds is represented by n and the regression coefficient of digital finance is being queried δ .

4.3. Facts of data and analysis of statistics

We use panel data from 294 prefectural towns from 2010 to 2018 to examine the impact of digital financing on the advancement of green technology innovation. The Institute of Digital Finance at Peking University derives the digital finance index. The statistics about educational spending, government transfer payment, financial income, GDP, and number of residents are sourced from the China Metropolitan Statistic Yearbook. The data on financial constraints were obtained from the Wind information database. The information on investments in pollutant prevention is sourced from the China Environmental Yearbook. Table 2 displays the descriptive statistics findings for the variables computed using STATA.

Table 2. Descriptive Statistics.

Variable	Mean	Std. Dev	Min	Max
GTI	0.649	0.125	0.255	1.000
NDF	143.867	57.846	17.020	275.470
HC	7.300	0.533	4.218	9.467
GTR	0.351	0.177	0.048	1.000
GDP	6.651	15.755	0.423	632.166
ERT	0.023	0.008	0.013	0.031
EC	0.629	0.346	0.059	4.329
SA	3.873	0.402	0.724	5.582
KZ	0.661	0.509	0.010	2.666

Variable	Mean	Std. Dev	Min	Max
ISP	0.405	0.852	0.001	10.441
MD	0.333	0.076	0.070	0.4552

5. Empirical analysis

5.1. Conduct an objective regression study.

We use a fixed-effects model to analyze the influence of technological financing on the advancement of green technology innovation. Table 3 demonstrates a clear positive correlation between digital finance and innovations in green technologies despite control variables and the control of time and location fixed effects.

Table 3. Outcomes of reference estimate.

Variables	(1)	(2)	(3)
NDF	0.029*** (0.008)	0.100*** 0.003)	0.0198** (0.009)
cons	0.576*** (0.040)	0.239*** (0.039)	0.601*** (0.057)
Control variables	No	Yes	Yes
Time fixed effect	Yes	No	Yes
Region fixed effect	Yes	Yes	Yes
Obs	2012	1973	1973
R^2	0.699	0.700	0.698

According to Column (3) of the third table, digital financial growth has a considerable contribution to green technology innovation at a 5% level of significance. The regression coefficient is 0.019. Each 1% rise in digital financial development corresponds to a 1.9% growth in the number of trademarks for green technology innovation. This outcome confirms hypothesis 1, suggesting that the advancement of green technology relies on having enough consistent financial resources. Additionally, digital finance addresses the limitations of traditional finance in allocating resources by utilizing technological innovations to align better both the need for funding and the inventory of funding. This improves productiveness in utilizing capital resources and reduces the monetary limitations confronting green technology innovation.

5.2. Robustness tests

5.2.1. Endogeneity test

This study comprehends that the previous regression model may be affected by endogeneity problems. Endogeneity arises when an autonomous variable (digital finance) and the dependent variable (green technology innovation) have a reciprocal causality connection or when the uncontrolled variable is associated with unobserved elements in the model. These factors may result in outcomes that are influenced by prejudice.

The research project examines two primary factors that could lead to endogeneity. Inverse causation may be present. The implementation of green technology innovation, characterized by its substantial capital requirements and extended return upon investment periods, has the potential to encourage a rise in digital financial transactions. Organizations with robust green technology efforts may appeal to digital financing companies more. Furthermore, there may be neglected factors that impact both digital finance and green technology innovation, which must be accounted for in the model. Although control factors are used to reduce this issue, it is only feasible for some components, which may impact the reliability of the results.

In order to account for the possibility of endogeneity, this study utilizes the variable of interest (IV) approach. An operational variable must satisfy two essential conditions:

Significance: It must strongly correlate with the independent variable (digital finance).

Homogeneity refers to the condition when a variable is not directly associated with the error term in the model.

The selected instrumental variable is the spherical distance (SPH) from each city to Hangzhou, which serves as the main office for Alipay, a prominent digital banking company. Alipay's commercial reach and growth were more widespread in Zhejiang and its neighboring regions than innovations in China.

The primary data used in this work is panel data, consisting of observations collected over time. In contrast, the SPH distance variable is cross-sectional, meaning it is static and does not vary over time. To resolve this discrepancy, the study employs a panel instrumental variable approach, similar to the one used by (Sarabdeen, Elhaj, and Alofaysan 2024). This is accomplished by calculating the product of the SPH radius for every city and the national average city digital financial development level for each year.

The endogeneity test findings, which are not demonstrated here, justify the selected strategy. The Wald test result (302.03) suggests that the SPH variable is not a weak instrumental variable. Furthermore, the p-value of the F-test is 0, indicating a statistically significant correlation. These results confirm the effectiveness of the variable of interest and indicate that the growth of digital finance has a beneficial effect on the invention of green technology.

This study utilizes the variable being studied technique to address possible endogeneity problems and enhance the reliability of the estimated association between digital finance and green technology innovation.

Table 4: Results of the Endogeneity Test.

Variables	**IV: Spherical Distance**		**IV: First-OLT**	
	Phase II	**Phase I**	**Phase II**	**Phase I**
NDF	1.6390*** (0.155)		0.288*** (0.040)	
SPH		−0.066*** (0.005)		
L.DFN				0.611*** (0.030)
cons	−3.299*** (0.357)	2.788*** (0.14)	−0.677*** (0.122)	1.886*** (0.099)
Control variables	Yes	Yes	Yes	Yes
Obs	1972	1972	1698	1698
Wald Test		302.03		782.88
R^2	0.237	0.930	0.339	0.899

This study adds to our knowledge of how technological infrastructures and networking facilities are essential to adequately operating digital banking. In addition, the growth of a well-established tangible economy supports expanding and enhancing a more extensive and profound digital monetary environment. The present state of digital finance undeniably shapes its future progress within a particular area. However, the effect of digital finance in prior eras on contemporary advancements in green technology may be more complex. This attribute is well-suited to meet the criteria for qualified external variables.

Thus, we use the first-order lagged term of the digital finance indicators (digital finance in the prior period) as the explanatory variable. Table 4 (unavailable) verifies a direct association between this factor and present digital finance. The Wald test statistic (792.96) surpasses the threshold value, suggesting that the lagged term is not a weak explanatory variable. Moreover, the F-test p-value of 0 indicates a statistically significant connection. The second-stage regression analysis, using the lagged term as an explanatory variable, demonstrates that digital finance substantially impacts green technology innovation promotion.

This technique enhances the research by addressing questions related to possible endogeneity and further supports the favorable impact of online banking on breakthroughs in green technology innovation.

5.2.2 Quantile regression.

We used quantile regression to enhance our comprehension of the correlation between digital finance and green technology innovation at all stages of invention. This methodology assists with evaluating the resilience of our conclusions to any anomalies in the data.

Table 5 demonstrates that digital finance has a substantial and favorable influence on the advancement of green technology innovation at all levels of measurement, which is consistent with our prior findings. Nevertheless, a compelling structure becomes apparent when analyzing the regression coefficients within each quartile. The coefficients first rise, indicating a more pronounced impact of digital banking on locations with modest green technology innovation. These places possess the highest capacity to get advantages from the advancement of digital financial services. As we approach the upper quartiles (areas with very high innovation), the coefficients exhibit a pattern of decline. This suggests the presence of declining maximum refunds, whereby more advancements in digital finance have a less significant impact on existing capacities for development in green technology.

This study enhances the understanding of the correlation between digital finance and green technology innovation by including quantile regression. The results indicate that digital finance substantially impacts fostering development in green technology, particularly in places with modest inventiveness.

Table 5. Results of the Quantile regression .

Variables	**Quantile of 0.1**	**Quantile of 0.5**	**Quantile of 0.9**
NDF	0.079*** (0.018)	0.235*** (0.015)	0.111*** (0.014)
cons	0.175*** (0.061)	−0.144*** (0.059)	0.485*** (0.050)
Control variables	Yes	Yes	Yes
Time fixed effect	Yes	Yes	Yes
Obs	1974	1974	1974
R^2	0.322	0.250	0.361

5.2.3. Excluding localities and provincial governments

Due to their constitutional benefits, Chinese localities and province cities possess a comparatively elevated organizational status, giving them more excellent avenues for communal assets. The unique attributes of growing economies in various locations might impact the correlations across variables. To assess the reliability of the regression findings, the data from localities that have direct oversight by the federal authorities and province cities are excluded.

The revised regression coefficients are shown in Table 6. Digital finance continues to strongly encourage the development of innovative green technologies.

Table 6. Regression results for index replacement, eliminating municipalities and provincial capitals.

Variables	Elimination of local authority entities and local administrative centers	Augmentation of the independent variable	Augmentation of the dependent variable
DFN	0.018** (0.009)	0.0112*** (0.005)	0.008*** (0.002)
cons	0.560*** (0.051)	0.561*** (0.039)	0.045** (0.017)
Control variables	Yes	Yes	Yes
Time fixed effect	Yes	Yes	Yes
Region fixed effect	Yes	Yes	Yes
Obs	1788	1972	1978
R^2	0.918	0.701	0.023

5.2.4. Transfer of indices

We conducted robustness checks to confirm the trustworthiness of our findings by collaborating with the dependent and independent variables in the regression research.

New Independent Dimension's replacement

According to the new financial model, we understand that an essential aspect of the expansion of digital finance provincially is the variety of safeguards for digital investments, indicating suitable services for customers. Therefore, we substitute the original digital finance index with a parameter representing the breadth of services. Table 6, which is not shown here, demonstrates the significant impact of digital funding on the advancement of green technology. In line with our previous discoveries, the coefficient has a value of 0.010 and is statistically significant at the 1% significance level.

Modifying the dependent variable:

The prior studies focused on the dependent variables of usability models trademarks alongside uses for green technology ideas. If economic variables, such as growth in GDP, influence the overall number of innovations submitted, there could be inventions unrelated to green technology. The results of the regression analysis may be

biased due to this factor. To address this problem, we recalculated the model in Table 6 (presented here) using the dependent variable that measures the proportion of inventions for green technology compared to the overall number of innovation and utility model trademarks. The results have remained unchanged. Even after considering any potential biases in recording behavior, it is evident that digital finance has a positive and statistically significant impact on the development of green technology innovation. The coefficient value is 0.005, with a significance level of 1%.

This research enhances the credibility of the core assertion: digital finance plays a crucial role in driving advancements in green technology innovation. It operates this by performing rigorous tests to assess the system's resilience, utilizing various variable classifications.

5.3. Assessment of heterogeneity

5.3.1. Broad enterprise

The article explores the potential impact of digital financial growth on promoting innovation in green technology firms. The data primarily focuses on authorized organizations, whereas "small-scale enterprises" are those with operating income less than the whole sample. The term "typical medium-sized enterprises (SMEs)" may not appropriately characterize these firms.

Smaller firms often need more financing options, limitations on credit ratings, and concerns about their ability to repay loans. These issues may restrict their capacity to raise financing. One potential solution might be the expansion of digital financial services, which could assist smaller firms in overcoming the discrepancy in data when they are looking for capital. Organizations may augment their level of green technology innovation by using digital finance, which provides broader financing opportunities and enhances the utilization of funding for development and research investments. In contrast, larger enterprises often have more resource options and better availability through traditional financing channels. Consequently, they may be less impacted by financing fluctuations due to the increase in digital banking.

Delving more thoroughly into this matter, the enterprises' sample was divided into two groups based on the average operational turnover value. The findings are shown in Table 7 (not seen here). The results indicate that digital financing is a better way of promoting green technology innovation among smaller-scale firms. The impact of this demographic is very substantial, with a regression coefficient of 0.066 and a statistical significance at the 1% level. In contrast, the larger-scale commercial organization has a smaller regression coefficient.

(Weiran Cai Zengjie Yao 2023) discovered that digital finance is much more equitable and may more effectively enhance the development of green technology in regions with less-developed traditional financial systems. Our findings are consistent with that. To mitigate financial impoverishment, digital finance can potentially enhance its services for enterprises in the "long tail" category. Due to the limited financial means of smaller enterprises, the comprehensive impact of this might be of great use to them.

This research illuminates the potential of digital finance to assist smaller firms, specifically in developing green technology. It does this by examining the impact of digital finance on the invention of green technology in enterprises of different sizes.

Table 7 conveys the regression findings across different enterprise scales.

Variables	**Large-scale enterprises group**	**Small-scale enterprises group**
NDF	0.047*** (0.004)	0.077*** (0.002)
cons	0.400*** (0.013)	0.289*** (0.008)
Control variables	Yes	Yes
Time fixed effect	Yes	Yes
Region fixed effect	Yes	Yes
Obs	1199	10,832
R^2	0.611	0.679

5.3.2 The breadth of the industrial sector

Utilizing manufacturer clusters may expedite the advancement of green technology innovation. China is the global leader in the industrialization process, making it the perfect example to illustrate this relationship. (B. Li et al. 2022) state that industrial activity in their country plays a dual role. It serves as the fundamental pillar of their economy and also as a hub for advancing environmentally friendly technological innovations. The progress of green innovation may be improved if conventional bankers, who prioritize risk avoidance and revenue generation, are willing to provide funding for this transformation. Digital money may be beneficial in such circumstances. Through digital finance, companies are empowered to allocate resources towards adopting eco-friendly technologies by accessing novel avenues for funding and enhanced financial guarantees.

Indisputable evidence suggests that digital finance has a more significant impact on regions with a large concentration of industrial jobs. These centers are bustling with innovative firms. In our research, we divided the participants into

two distinct groups based on the median value. We used an industrial scale, which measures the proportion of total pay related to production compared to all industries. Cities with an "abundant supplier share" (above the average) have shown a stronger positive correlation between digital finance and green tech innovation. The regression coefficient, a statistical measure of the amount of influence, indicates this. At a significance threshold of 1%, the coefficient in our case is 0.056, indicating statistical significance. This statement leads to two significant inferences:

These places house factories that actively engage in advances in technology. Digital finance successfully broadens its financing opportunities and provides the necessary guarantees to support its commitment to green tech innovation.

Table 8: Regression estimates across various manufacture dimensions.

Variables	Group that comprises a significant proportion of production operations	Group that comprises a small proportion of industrial activities
NDF	0.054*** (0.015)	0.012 (0.009)
cons	0.376*** (0.071)	0.489*** (0.070)
Control variables	Yes	Yes
Time fixed effect	Yes	Yes
Region fixed effect	Yes	Yes
Obs	890	1080
R^2	0.820	0.630

5.3.3. Municipal Administration's Regulation Capability

Supplementary to the rise in funding from digital finance, the effectiveness of regional governments represents another crucial element in promoting green technology innovation. Regions with solid municipalities have a notably more significant positive impact of digital finance on advancements in green technology. This is evident via their capacity to manage financial matters, enforce rules, and maintain stability. The research used (Yi et al. 2017)(Alexey Kudryavtseva Svetlana Samarina 2023) methodology to evaluate governance capacity across four domains: regulatory quality, government efficiency, the judiciary, and illicit activity prevention. According to this evaluation, the study categorizes locations into good and bad governance classifications. The results shown in Table 9 indicate that in regions with robust municipal administration capacities, digital finance has a much more positive effect on the

advancement of green technology innovation. Effective leadership in these domains enables the efficient allocation of resources towards eco-friendly initiatives, reduces income disparities that could hinder inventiveness, and establishes safe atmospheres with resilient technological defense, all of which promote the progress of scientific discovery in green technology. In addition, according to (G. Li, Guo, and Di 2021), proficient local governments may use taxes to attract private investment and enhance the positive impacts of digital finance on green technology innovation. In summary, to use digital finance for green tech innovation effectively, two tactics are necessary: firstly, the provision of appropriate financial instruments, and secondly, the establishment of a supportive environment via solid regional governments.

Table 9. Evaluations of regression under various regional governing capabilities.

Variables	**Group with a high level to govern capability**	**Group with a lower level to govern capability**
NDF	0.037* (0.017)	0.011 (0.011)
cons	0.532*** (0.073)	0.653*** (0.073)
Control variables	Yes	Yes
Time fixed effect	Yes	Yes
Region fixed effect	Yes	Yes
Obs	979	989
R^2	0.624	0.700

5.3.4. Size of trade organized by the government

State-owned enterprises (SOEs) pose specific challenges for digital finance, hindering the advancement of green tech innovation. Their prioritization of welfare initiatives, government-supported salaries, and complex processes may hinder their ambition to innovate and create new technology. In contrast, private enterprises are prone to be at the forefront of environmentally friendly innovation since they are motivated by financial gain. In addition, due to their economic structure, state-owned enterprises (SOEs) often benefit from lower financing costs and have access to diverse funding choices (Shanshan Deng Feng Yuan 2023). Consequently, private firms rely less on digital finance than public enterprises since the latter benefit more from its broader financing options.

In order to conduct a more in-depth study, we computed the degree of authority exerted by the financial system by multiplying the total pay allocated to residents by the proportion of earnings contributed by employees of state-owned enterprises. Table 10, which divided the sample into two groups based on this criteria, displays a clear and noticeable trend. Digital finance's presence dramatically enhances green technology development in regions with a lower concentration of state-owned enterprises (SOEs). In regions where state-owned enterprises (SOEs) are dominant, the effect of their presence is statistically insignificant. This aligns with the findings of (Y. Zhang and Li 2022), which indicate that non-state-owned enterprises benefit the greatest from digital finance by accessing more cash resources and increasing investments in environmentally friendly technological advancements. Our analysis reveals that regions with a less significant state-owned sector would have more advantages in green tech innovation via the implementation of digital finance. This is particularly true in locations where startups are the primary drivers of technical advancements.

Table 10: Regression estimates across various SOEs

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Variables	**Group with a low % of SOEs**	**Group with a high % of SOEs**
NDF	0.042** (0.015)	−0.002 (0.014)
cons	0.781*** (0.081)	0.516*** (0.055)
Control variables	Yes	Yes
Time fixed effect	Yes	Yes
Region fixed effect	Yes	Yes
Obs	790	1178
R^2	0.778	0.599

5.3.5. Frequency of emitting pollutants

Analyses reveal that pollution levels specific to certain regions have an unforeseen influence on the effectiveness of digital finance in promoting innovation in green technology, regardless of the influence of local government and financial arrangements. This phenomenon occurs because different regions are exposed to different types of environmental circumstances.

To determine this impact, we measured the frequency of pollutant emissions, which refers to the total amount of recyclable materials produced by industries as a proportion of a region's Gross Domestic Product (GDP). Table 11 reveals a clear trend when we divide the participants into two groups based on the mean extent of emissions: one group with high sensitivity and another with low severity. In regions characterized by frequent emissions, digital

funding plays a significant role in promoting innovation in green technology. In regions with few greenhouse gases, the effect is absent.

This variance may be attributed to the pressures experienced by towns located in highly polluted areas. They are frequently driven by incentives based on their external management and face growing pressure to minimize environmental damage. Potential outcomes include implementing more rigorous environmental regulations, which require polluting industries to adopt measures to reduce pollutants and adopt sustainable green technology. Corporations in these regions have a paradoxical situation: they must engage in innovative practices to contribute to environmental sustainability, but environmentally friendly approaches may entail significant risks, expenses, and a prolonged period before generating sufficient returns on investment. This needs a consistent influx of capital in addition to access to diverse sources of funding. These requirements facilitate the progress and widespread use of digital financial instruments.

Digital finance is particularly effective in regions with a high degree of pollutant concern since it assists in funding green innovation initiatives undertaken by firms generally under significant scrutiny for their sustainability practices.

Table 11: Regression estimates for various amounts of pollutant emissions.

Variables	**Clusters noted for a substantial amount of pollutant emission rate**	**Low-emission frequency grouping**
NDF	0.029** (0.017)	0.015 (0.009)
cons	0.399*** (0.090)	0.600*** (0.070)
Control variables	Yes	Yes
Time fixed effect	Yes	Yes
Region fixed effect	Yes	Yes
Obs	590	1401
R^2	0.679	0.699

5.4. Research of the mechanism

Digital finance affects green technology innovation. Digital finance minimizes expenditures on transactions and statistical discrepancy, reducing green subject financing constraints and supporting green technology innovation.

Digital finance may improve logistical finance, cut production and green innovation costs, and expand industrial scale. Digital finance may locate high-efficiency industries, send them social capital and other high-quality components, update manufacturing, and stimulate local green technology innovation. The research will explore how digital finance affects innovative green technology in FCs, industrial structure upgrading, and MD.

financing constraints (FCs)

Green tech innovation faces a significant challenge in the form of financing limits, which may be effectively addressed via digital finance. Conventional banks often encounter an informational gap when their creditors need a complete grasp of their clients. Due to this, green technology businesses may need help securing financing. (Aamir Fuinhas José Alberto Rapposelli 2023) argue that digital finance helps bridge this gap by improving data transmission in the credit system. Additional opportunities for financing green technology innovation may arise.

To further examine this impact, we analyzed data gathered by publicly traded companies from 2010 to 2018. Our study specifically investigated the influence of digital finance on the development of green technology innovation, with an accent on finance-related obstacles. The total number of trademarks granted for environmentally friendly ideas and practical applications was used to assess an organization's capacity to innovate in green technology. The KZ index and the SA index are commonly used indicators for assessing finance restrictions at the corporate level. The KZ index incorporates many factors, such as free cash flow, Tobin's Q, and the debt-to-equity ratio. On the other hand, the SA indicator considers firm size and age.

Our research findings, as shown in Table 12, deliver convincing proof that digital finance can alleviate financing constraints and stimulate the development of environmentally friendly technology. The data indicate a statistically substantial negative link between digital finance and KZ and SA stocks. A more accessible argument would be that as digital finance advances, firms have fewer limitations in obtaining funding. Furthermore, a negative association exists between the innovation of green technology and the indices measuring restrictions in finance. According to research, removing financial limitations significantly promotes innovation in green technologies.

Essentially, digital finance simplifies obtaining money, broadens the range of financing choices, and alleviates financial pressure on enterprises. Consequently, this provides them with a safety net and financial resources to engage in innovative green technology, thus enhancing a region's overall capability for green innovation.

Table 12: Regression estimates for the FCs

Variables	**KZ Index**		**SA Index**	
	FCs	**GTI**	**FCs**	**GTI**
NDF	−0.019** (0.011)	0.081*** (0.015)	−0.156*** (0.004)	1.411*** (0.462)
FCs		−0.040*** (0.013)		−7.830*** (0.489)
cons	0.821*** (0.054)	−0.299*** (0.079)	−2.999*** (0.030)	21.267*** (3.000)
Control variables	Yes	Yes	Yes	Yes
Time fixed effect	Yes	Yes	Yes	Yes
Region fixed effect	Yes	Yes	Yes	Yes
Obs	10,602	10,489	16,940	11,744
R^2	0.035	0.059	0.072	0.046

5.4.2 (ISR)

Another beneficial aspect of digital finance is the enhanced efficacy of localized green production and investing in green technologies. Directing funds towards sustainable firms enables more effective use of supplies. Financial services can also restrict investment options to only those industries in the green sector with a high level of effectiveness. Lastly, it promotes innovation and facilitates greater access to financial resources, motivating enterprises to adopt environmentally-friendly production methods and ultimately enhancing revenue. To calculate this impact, we will use Production Structure Rationalization (PRS), which measures the level of alignment between enterprises and their properties and their efficiency in converting inputs into outputs. A practical approach to assessing the influence of digital finance on the development of a more environmentally friendly and productive industrial setting is by examining the PRS.

$$E = \sum_{i=1}^{n} |(Y_{it}/L_{it})/(Y_t/L_t) - 1| = \sum_{i=1}^{n} |(Y_{it}/Y_t)/(L_{it}/L_t) - 1| \quad (6)$$

The variables t, n, Y, L, and I represent inputs labor, industrial sector, time, and the number of sectors in the industry, respectively. A reduced industrial variance corresponds to a more rational industrial organization. The PRS index is derived from the extended equation for E.

$$PRS = -\sum_{i=1}^{n}(Y_{it}/Y_t)\cdot|(Y_{it}/L_{it})/(Y_t/L_t)-1| \qquad (7)$$

This indicator uses adjusted production to show how vital every business is. A lower coefficient E indicates a healthier business model, whereas a bigger PRS suggests a more robust economy.

Green technology innovation is being promoted by the upgrade of factories by digital finance, as shown in Table 13. Evidence from the real world supports the second theory. The impact of digital finance on upgrading industrial structure is favorable; at the 1% significance level, the digital finance coefficient is 0.571. The capacity to innovate will rise by 0.3 percentage points for each percentage point advance in modernizing factories. The regression findings show that digital finance promotes green technology innovation via industrial structure upgrading, with the mediation effect accounting for 7.12%. Improved stimulation of green technology innovation by organizations will be a result of digital financial development's promotion of locale industrial structure upgrading, enhanced requirements for power and energy efficiency in businesses, and strengthening of business scale and equipment dissemination (Yaqub and Alsabban 2023).

Table 13: Regression estimates for ISP and MDM.

Variables	**ISP**	**GTI**	**MD**	**GTI**
NDF	0.603*** (0.151)	0.017** (0.0010)	0.010*** (0.003)	0.020** (0.009)
ISP		0.003* (0.002)		
MD				0.289*** (0.034)
cons	0.015 (0.961)	0.517*** (0.051)	0.264*** (0.030)	0.399*** (0.050)
Control variables	Yes	Yes	Yes	Yes
Time fixed effect	Yes	Yes	Yes	Yes
Region fixed effect	Yes	Yes	Yes	Yes
Obs	1979	1979	1979	1979
R^2	0.041	0.701	0.135	0.698

5.4.3. Growth for manufacture

(Mengzhen Ding Xingong Choi 2023) contend that manufacturing is very productive. (Cao et al. 2021) and (Liu and Wang 2023) discovered that the scientific basis of digital finance has enhanced the viability of green technology innovation. This is achieved by enabling collaboration in developing services and products, effectively connecting every component of financial generation, and aiding progress in the manufacturing sector through greater use of operational variables such as financial resources. A higher production growth rate is indicated by an increased level of industrial growth, which is characterized as the percentage of total value generated derived from production. By promoting the expansion of industrial firms, digital finance has the potential to significantly contribute to developing environmentally friendly technologies on a regional level, as seen in Table 13. That supports the validity of 2c. Increasing digital finance by one unit leads to a 0.0010-unit increase in industrial growth, indicating that digital finance promotes industrial progress. Industrial growth, shown by a regression value of 0.289, has the potential to stimulate development in sustainable innovation. Given this circumstance, it can be inferred that the progression of "digital finance - industrial growth - green technology innovation" is influenced by a particular purpose. Enhancements associated with production may further enhance the positive influence of digital finance on advances in green technology. The negotiation impact % is 10.32%, which indicates a significant regulatory effect.

6. Additional Discussions

China's revolutionary ecological approach includes environmental sovereignty, a framework for environmental governance that blends centralized power with autonomy. The federal government allocates financial resources to municipalities and states, influencing their green policy-making. The system has experienced several phases of change, from its first stages to its current state of laws and incentives to promote provincial environmental leadership. The federal government employs a "one-vote vetoed" process and conducts accountability checks to guarantee that cities and states adhere to environmentally sustainable legislation. An avenue in which digital finance might promote innovation in environmentally friendly technology is by prioritizing sustainability. Investments made by local and central authorities to manage pollution may serve as an alternative to environmental decentralization since they demonstrate the ongoing transfer of responsibility between these two levels.

$$ED_{it} = \frac{CEI_{it}/SA_{it}}{LEI_t/PA_t} \cdot (1 - GDP_{it}/GDP_t) \quad (8)$$

Where LEI amounts spent regionally on preventing environmental pollution and CEI is the territorial investment in pollutants control located.

The value TA represents the country's overall population, SA value represents the number of people living in a specific area, and the GDP value represents the country's entire economic output. The variable "t" represents time, whereas "i" represents region.

The decentralization of regional environmental laws enhances innovation in green technologies. Stringent consumer regulations compel corporations to embrace more environmentally friendly methods, necessitating the development of new technology. In addition, municipal governments may use digital finance (on the supplier side) to identify potential environmentally friendly companies, enhance financial accessibility, and reduce risks associated with entrepreneurship.

The paper employs a threshold regression model to examine how environmental decentralization enhances the beneficial effects of digital finance on the advancement of green technology innovation. The findings shown in Table 14 demonstrate a twofold threshold effect, indicating that the impact of digital money varies at distinct degrees of environmental decentralization. These thresholds occur at 0.629 and 1.051. We will categorize these impacts into three categories according to these specific thresholds to analyze these impacts.

Table 14. Threshold Regression Model

Threshold Quantity	**Threshold Value**	**f-value**	**p-value**	**1%**	**5%**	**10%**
Individual Threshold	0.629	96.009	0.000	32.580	23.710	20.607
Pair Threshold	1.051	98.289	0.000	28.701	20.950	18.124
Additional threshold	0.071	85.090	0.773	189.351	170.040	149.405

The analysis indicates that when municipal governments have the liberty to make sustainability decisions, the positive effects of digital finance on localized green tech innovation are improved. Previous research proved the veracity of this statement. The impact of digital finance experiences significant changes at two crucial stages of democratization: from 0.629 to 1.051. The effect is beneficial but modest, falling under the first threshold. The impact is magnified

inside the two boundaries. Above the subsequent obstacle is a significant increase in the effect, where a 1% increase in digital finance results in a substantial 10.33% growth in sustainable technologies. Integrating local environmental regulations with digital financial technology makes it possible to more efficiently direct resources towards businesses with significant upsides or those causing pollution. This will enable us better to align funding with consumer appetite for green technologies, leading to improved utilization of resources for environmentally friendly innovation.

Table 14. Threshold Regression Model

Variables	**(1)**	**(2)**
NDF·I (ED≤ 0.629)	0.076***	0.092***
	(0.002)	(0.004)
NDF·I (0.629<ED≤ 1.051)	0.095***	0.097***
	(0.003)	(0.004)
NDF·I (ED>1.051)	0.087***	0.099***
	(0.003)	(0.004)
cons	0.339***	0.289***
	(0.008)	(0.043)
Control variables	No	Yes
Obs	2004	2004
R^2	0.678	0.689

7. Conclusion and implications

The research project examined the period from 2010 to 2018 to measure the impact of digital finance on the advancement of green technology innovation in China. The findings demonstrate that digital finance has a positive impact by enhancing the ability to innovate in green technology across various locations, and this influence remains consistent throughout diverse assessments.

Nevertheless, the impact will vary across different businesses and sectors. Smaller firms seem to be seeing more success in promoting green innovation via digital finance. The positive influence is particularly evident in regions with a high concentration of industries and privately owned firms, as well as in industries that generate significant levels of pollution. In addition, the paper identifies the specific methods by which digital finance achieves this objective: it assists enterprises in meeting their financial requirements. It promotes alterations to the structure of businesses in the sector in question.

The research suggests that environmental decentralization might have an impact. The positive impact of digital finance on community innovation is enhanced when municipalities have more autonomy in environmental regulation (increased decentralization). Governments may use digital finance channels to enhance their ability to finance green tech innovation activities.

The paper proposes a comprehensive strategy for regulators to harness the advantageous impact of financial technology for environmentally friendly innovations.

Priority should be given to the modernized banking sector. Traditional financial institutions must transition towards digital finance operations. Financial institutions and other entities may use digital technologies to improve online and offline recruiting processes, streamline lending processes, identify environmentally conscious entrepreneurs with potential, and optimize firms' utilization of funding for scientific investigation. Another way to enhance the structure is to foster development within the virtual financial sector by promoting competition among companies. This will be accomplished via various technologies, applications, and commodities.

Another factor to consider is the need to provide targeted incentives for ecologically innovative practices. Industrialists and businesses may reap the advantages of increased investment in technological advances via tailored strategies. This may include tax credits, financial aid, and incentives designed explicitly for environmentally-friendly businesses. Securing money for innovation in the early phases is crucial for industrial and company owners. Therefore, it is essential to establish a robust beginning financing framework and marketplace services as quickly as feasible. One example of government-managed investments in equities is via methods like crowdfunding or angel funding. These procedures facilitate innovation by addressing the disparity in information.

Finally, the study provides evidence of a modified environmental decentralization model that balances centralized and regional oversight. In order to enhance the capacity of municipalities to perform environmental governance, it is necessary to provide them more jurisdiction over environmentally related responsibilities, such as personnel deployment and allocation of financial resources. However, to ensure sustainability standards are maintained, it is imperative to establish more robust centralized environmental control alongside the decentralization process. As a component of this initiative, there will be an increase in the frequency of evaluations, implementation of specialized monitoring systems for municipal environmental conditions, and a heightened emphasis on sustainability achievements in the evaluations of local administrations. Ultimately, the collective implementation of these measures

will promote emissions control, accelerating the development of eco-friendly technologies and enhancing the efficiency of environmental investments.

The paper admits several flaws, revealing opportunities for additional investigation. Initially, the provided information only pertains to NYSE-listed companies, excluding any insights on how small and medium-sized enterprises (SMEs) utilize digital finance to promote green innovation. Future research may provide more insights into how digital finance benefits SMEs in this industry. Moreover, additional examination of the mechanism connecting digital finance to enhancements in business models is necessary, regardless of whether this connection was demonstrated in the study. The degree to which digital finance contributes to these trends is still being determined and requires more study for a definitive response.

Finally, the study examined environmental decentralization through a top-down viewpoint, assessing the comparative capabilities of the federal government, the states, and the municipalities. Examining the impacts of orthogonal environmental decentralization, which focuses on the jurisdiction of towns and cities in decision-making compared to national environment agencies, might contribute to bridging the knowledge gaps in our present comprehension. It is important to consider this scenario to better understand how transversal decentralization impacts green technology innovation via digital finance.

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