Digital Inclusive Finance and Urban Green Technology Innovation: Evidence from 276 Chinese Cities, 2014–2024

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Abstract. Green technological innovation is crucial for urban green transition, but evidence at the city level regarding the role of digital inclusive finance remains limited. Using panel data from 276 Chinese cities spanning 2014 to 2024, this study employs a two-way fixed-effects model to examine the impact of digital inclusive finance on urban green technological innovation, the mediating role of economic development levels, and heterogeneity across city tiers. The results indicate that digital inclusive finance significantly promotes urban green technological innovation, with a stronger impact on innovation quality than on innovation quantity, and that economic development level plays a partial mediating role. The findings remain robust after excluding municipalities directly under the central government, introducing lagged terms, and replacing explanatory variables. This promotional effect is most pronounced in first-tier and fifth-tier cities. These findings provide evidence for improving digital financial infrastructure and implementing differentiated regional policies.

Keywords: Digital inclusive finance; green technology innovation; urban economy

1 Introduction

Against the backdrop of the “dual carbon” goals and high-quality development, green technological innovation has become a crucial pillar for cities to achieve green transformation[1]. Existing literature has largely focused on micro-level enterprise entities, and research on the impact of digital inclusive finance on corporate green technology innovation has accumulated a substantial theoretical foundation. Although a few macro-level explorations have emerged in recent years, most remain confined to provincial-level analyses of technology diffusion. Empirical evidence regarding the heterogeneous characteristics of urban green technology innovation clusters and their transmission pathways is relatively scarce, and few studies have examined the relationship between digital inclusive finance and the quantity and quality of urban green technology innovation. Based on this, this paper uses 276 Chinese cities from 2014 to 2024 as a sample to investigate the impact of digital inclusive finance on urban green

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technology innovation, the mediating role of economic development levels, and the heterogeneity across different city tiers.

2 Theoretical Background and Hypotheses

2.1 Digital Inclusive Finance and Urban Green Technology Innovation

Green technology innovation has two main benefits. First, it creates positive knowledge spillovers. Second, it mitigates negative environmental externalities. However, there are usually three problems with this. First, there are very high financing thresholds. Second, there are long investment cycles. Third, there are mismatches between risk and return. So, it depends a lot on having the right financial support. Digital inclusive finance uses technologies like big data and cloud computing to overcome the physical and cost limitations of traditional finance. It helps with money issues, makes information more equal, and helps put money into the best places. Digital platforms can guide money toward environmentally friendly sectors through mechanisms that determine prices. Diversified investment and dynamic monitoring reduce uncertainty in green innovation projects[2].

H1: Digital inclusive finance has a significant positive effect on urban green technology innovation.

2.2 Quantity vs. Quality of Green Innovation

Green technology innovation is not a single thing; it includes both more of the same technology and improvements in quality. High-quality green innovation is usually more expensive and takes more time to develop than quantity-based innovation. Digital inclusive finance does more than just increase the total amount of money available; it also makes it more efficient to allocate financial resources. This means that more money is available for complex, R&D-intensive innovation activities. So, its main effect is to improve how innovation works[3]. It does this by shifting the focus from increasing the number of innovations to improving their quality.

H2: Digital inclusive finance has a stronger effect on the quality of green technology innovation than on its quantity.

2.3 Mediating Role of Economic Development

Financial development theory says that growing financial markets can lead to more money, new businesses, and improvements in industry. This can help the economy grow. In urban areas, economic development makes it easier to support green innovation. First, cities that are doing well economically can invest more in things like green infrastructure, R&D, and environmental management. Second, economic growth makes markets bigger, changes how people buy things, and increases demand for green products. This encourages companies to create new green products. Third,

higher levels of development are often linked to better talent, coordination between industries, and resources for innovation.

H3: Digital inclusive finance promotes urban green technology innovation through improving economic development.

3 Research Design

3.1 Sample Selection and Data Sources

This paper looks at cities in China that are at least prefecture-level, from 2014 to 2024. Some cities were not included in the study because they did not have enough data, their statistics were not reliable, or their boundaries changed. These cities were Tulufan, Sansha, Chaohu, and several others[4]. The final balanced sample includes panel data for 276 cities. The data on digital financial inclusion comes from the Peking University Digital Financial Inclusion Index, which was created by Guo and his team[4]. The data on green patents comes from the CNRDS database. Information about the economy and society at the city level is collected from different sources. These include the China City Statistical Yearbook, provincial statistical yearbooks, and statistical bulletins on national economic and social development for prefecture-level cities. Other related statistical materials are also used.

3.2 Model Specification

To examine the impact of digital inclusive finance on urban green technology innovation, this paper adopts a two-way fixed effects model:

$$GTI_{it} = \alpha_0 + \alpha_1 DFI_{it} + \alpha_2 Controls_t + u_t + \lambda_t + \varepsilon_t \quad (1)$$

where GTI_{it} denotes the level of green technology innovation in city i in year t; DFI_{it} is the digital inclusive finance index; $Controls_t$ is the vector of control variables, including population size, population mobility, economic development, mobile-phone penetration, and human capital; u_t and λ_t represent city and year fixed effects; and ε_t is the stochastic error term. A significantly positive α_1 indicates that digital inclusive finance significantly promotes urban green technology innovation.

To understand how digital inclusive finance affects different types of green innovation, the paper uses green invention and utility-model patents as dependent variables. This helps to see if the effect of promotion differs between innovation quality and innovation quantity.

To test the mediating effect of economic development, the following models are constructed:

$$ED_i = \beta_0 + \beta_1 DIF_{it} + \beta_2 Controls_{it} + u_i + \lambda_i + \varepsilon_{it} \quad (2)$$

$$GTI_i = \gamma_0 + \gamma_1 DIF_i + \gamma_2 ED_i + \gamma_3 Controls_i + u_i + \lambda_i + \varepsilon_i \quad (3)$$

Here, ED_irepresents the level of economic development, which is measured by the natural logarithm of the per capita regional GDP. The other variables are set in accordance with Equation (1). If β_1 in Equation (2) is significantly positive, digital inclusive finance promotes economic development. If γ_2 in Equation (3) is significantly positive and the coefficient on DFI is smaller than that in Equation (1), economic development is confirmed as a mediating channel through which digital inclusive finance further promotes urban green technology innovation. All estimations employ city-clustered robust standard errors to ensure the reliability of statistical inference.

3.3 Variable Definitions

Dependent Variable. Green technology innovation (GTI). This paper uses the level of urban green technological innovation as the dependent variable. Given that green innovation is primarily manifested in green intellectual property output, this study measures green technological innovation using the number of green patent applications filed in cities. To mitigate the effects of sample dispersion and outliers, the data is first added by 1 and then transformed using the natural logarithm. To further assess innovation quality, following the approach of existing studies[5], this paper categorizes green patents into the number of green utility model patent applications and the number of green invention patent applications, and uses these to test green technology innovation quantity (GTI Quantity) and green technology innovation quality (GTI Quality), respectively.

Core Explanatory Variable. Digital inclusive finance index (DFI). The present study employs the Peking University Digital Financial Inclusion Index, as proposed by Guo et al., to assess the advancement of digital inclusive finance at the urban level. This index comprehensively reflects the breadth of coverage, depth of use, and digital-service capacity of local digital finance, thereby capturing the availability, convenience, and inclusiveness of financial services.

Mediating Variable. The mediating variable is economic development (ED), measured by the natural logarithm of GDP per capita. This variable reflects the city's overall economic strength, market development level, and factor-carrying capacity. It is used to examine the economic transmission mechanism through which digital inclusive finance affects green innovation.

Control Variables. To deal with omitted-variable bias, this paper includes the following control variables. The population size of a city is measured by the natural logarithm of the number of people living there. This number is used to control for the effect of city size on green innovation. The population mobility rate is a way to measure population mobility. The population mobility rate is calculated using this formula: (resident population − registered population)/registered population. This rate tells us how much people move around and how much they are grouped together. The num-

ber of mobile phones for every 100 people in a city is a good way to measure mobile phone use. This number shows how well the city has information and communication technology, like cell phones, and how many digital applications people use. The human capital (Edu) of a city is measured by the ratio of students enrolled in regular higher education institutions to the total population at the end of the year. This ratio shows how much the city's population is learning and how much knowledge the city has.

4 Empirical Results and Analysis

4.1 Baseline Regression Analysis

Table 1 shows the results of the initial regression study on how digital inclusive finance affects innovation in urban green technology. The first three columns show the regression results without control variables. The last three columns include control variables. All models control for city and year effects. City-clustered robust standard errors are also applied.

The results show that the regression coefficient of the digital inclusive finance index (DFI) is positive and significant at the 1% level in all specifications, indicating that digital inclusive finance significantly promotes urban green technology innovation. After adding the control variables, both the sign and significance of the coefficient remain stable, suggesting that the baseline results are robust. More importantly, the coefficient of digital inclusive finance for green innovation quantity is consistently smaller than that for green innovation quality[6], indicating that digital inclusive finance provides stronger support for high-quality green innovation characterized by longer R&D cycles and higher technological thresholds by improving financing accessibility, enhancing resource allocation efficiency, and easing financial constraints in innovation activities[7]. Therefore, Hypotheses H1 and H2 are supported.

Table 1. Baseline regression results of digital inclusive finance on green technology innovation.

Variable	(1) GTI	(2) GTI Quality	(3) GTI Quantity	(4) GTI	(5) GTI Quality	(6) GTI Quantity
DFI	0.008837***	0.009211***	0.008429***	0.008837***	0.009212***	0.008454***
	(0.000215)	(0.000259)	(0.000227)	(0.000255)	(0.000307)	(0.000273)
Pop				0.178332	1.062284***	-0.038921
				(0.353225)	(0.373952)	(0.346178)
Flow				-0.162754	-0.293132*	-0.094925
				(0.159579)	(0.167161)	(0.145997)
Mobile				0.009187***	-0.006317***	0.011995***

				(0.001439)	(0.000921)	(0.001776)
Edu				-6.189711***	3.091105	-8.205336***
				(2.063736)	(2.844793)	(2.471601)
Constant	2.896468***	0.926916***	2.802935***	1.759832	-5.246935**	2.915405
	(0.052294)	(0.063167)	(0.055347)	(2.084066)	(2.209667)	(2.043065)
City FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
N	3036	3036	3036	3036	3036	3036
R^2	0.6429	0.5335	0.5556	0.6678	0.5476	0.5963

Notes: Standard errors are reported in parentheses. *** p < 0.01, ** p < 0.05, * p < 0.10.

4.2 Mechanism Test

To further identify the internal transmission path through which digital inclusive finance affects urban green technology innovation, this paper tests the mediating effect of economic development. The estimation results are reported in Table 2. Column (1) shows that the digital inclusive finance index (DFI) has a positive and highly significant effect on economic development (ED), indicating that digital inclusive finance significantly promotes urban economic growth. In Column (2), after economic development is included as a mediating variable, the coefficient of DFI remains significantly positive at the 1% level, while the coefficient of ED is significantly positive at the 10% level. At the same time, the coefficient of DFI becomes smaller in magnitude than in the baseline regression, indicating the existence of a partial mediating effect. Therefore, Hypothesis H3 is supported.

Table 2. Mechanism test results.

Variable	(2) ED	(3) GTI
DFI	0.003811*** (0.000092)	0.007994*** (0.000481)
ED		0.221054** (0.118114)
Pop	-0.381155*** (0.111301)	0.262588 (0.368110)
Flow	-0.011821 (0.053316)	-0.160141 (0.156738)

Mobile	0.000883*** (0.000202)	0.008992*** (0.001437)
Edu	0.842257 (0.825226)	-6.375895*** (2.081994)
Constant	12.204900*** (0.647571)	-0.938104 (2.856678)
City FE	Yes	Yes
Year FE	Yes	Yes
N	3036	3036
R^2	0.8301	0.6691

Notes: Standard errors are reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

4.3 Robustness Tests

To further verify the robustness of the baseline conclusions, this paper conducts a series of robustness checks, including excluding municipalities, using a lagged explanatory variable, and replacing the core explanatory variable.

Excluding Municipalities. Considering that municipalities directly under the central government possess distinctive characteristics in terms of resource endowment, financial development, and policy support, their inclusion may bias the baseline estimates. Therefore, Beijing, Shanghai, Tianjin, and Chongqing are excluded from the sample, and the regressions are re-estimated. The first three columns of Table 3 report the results. The coefficients of DFI remain significantly positive at the 1% level, indicating that digital inclusive finance still significantly promotes urban green technology innovation after excluding municipalities. In terms of coefficient magnitude, digital inclusive finance not only expands the scale of green innovation output but also contributes more strongly to the evolution of green innovation toward higher quality, which is consistent with the baseline findings.

Lagged Explanatory Variable. To further alleviate potential reverse causality, this paper replaces the contemporaneous DFI with its one-period lagged value and re-estimates the model. The last three columns of Table 3 present the results. The coefficients of the lagged digital inclusive finance index remain significantly positive at the 1% level. Moreover, the coefficient for green innovation quality is still larger than that for green innovation quantity. This suggests that even after taking possible time-lag effects into account, digital inclusive finance continues to significantly promote urban green technology innovation, especially its quality dimension. Therefore, the conclusions remain robust.

Table 3. Robustness tests based on excluding municipalities and a lagged explanatory variable.

Variable	(1) GTI	(2) GTI Quality	(3) GTI Quantity	(4) GTI	(5) GTI Quality	(6) GTI Quantity
DFI	0.014068***	0.027236***	0.013375***			
	(0.001587)	(0.001879)	(0.001594)			
L_DFI				0.007800***	0.008230***	0.007461***
				(0.000271)	(0.000334)	(0.000290)
Pop	1.164738***	1.123498***	1.118895***	-0.006862	0.727732	-0.246631
	(0.080398)	(0.078710)	(0.076615)	(0.420996)	(0.453823)	(0.410420)
Flow	0.478187***	0.438428***	0.535194***	-0.243697	-0.399350*	-0.146308
	(0.134888)	(0.146150)	(0.145834)	(0.208053)	(0.223667)	(0.181002)
Mobile	0.002023*	-0.001514	0.001892*	0.007125***	-0.008197***	0.009990***
	(0.001033)	(0.001341)	(0.000959)	(0.001158)	(0.001111)	(0.001506)
Edu	6.138163***	10.252480***	5.626099***	-4.074492**	6.912264**	-6.690983***
	(1.477603)	(1.850514)	(1.492214)	(1.946962)	(3.060217)	(2.390359)
Constant	-4.959149***	-8.451313***	-4.749072***	3.266118	-2.914910	4.549665*
	(0.459341)	(0.447936)	(0.443503)	(2.487707)	(2.680847)	(2.426436)
City FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
N	2992	2992	2992	2760	2760	2760
R^2	0.8109	0.8093	0.8000	0.5853	0.4585	0.5166

Notes: Standard errors are reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Replacing the Core Explanatory Variable. To further test robustness, the composite digital inclusive finance index is replaced by two alternative measures: coverage breadth (Cover) and depth of use (Depth). The results are reported in Table 4. Both variables have significantly positive coefficients at the 1% level. In addition, the effects on green innovation quantity remain smaller than those on green innovation quality. These findings suggest that the benchmark conclusions are robust to alternative measurements of the core explanatory variable.

Table 4. Robustness tests based on replacing the core explanatory variable.

Variable	(1) GTI	(2) GTI Quality	(3) GTI Quantity	(4) GTI	(5) GTI Quality	(6) GTI Quantity
Cover	0.007157***	0.007833***	0.006765***			
	(0.000224)	(0.000267)	(0.000239)			
Depth				0.008467***	0.007891***	0.007287***
				(0.000272)	(0.000349)	(0.000278)
Pop	0.585568*	1.461950***	0.356240	-0.094147	0.906323**	-0.325103
	(0.350145)	(0.365150)	(0.344412)	(0.398429)	(0.442702)	(0.384646)

Flow	-0.245797	-0.330728**	-0.185294	-0.394303*	-0.622345**	-0.298977
	(0.162139)	(0.161892)	(0.149707)	(0.209991)	(0.247069)	(0.184383)
Mobile	0.009217***	-0.006584***	0.012092***	0.010063***	-0.004860***	0.012726***
	(0.001470)	(0.000924)	(0.001818)	(0.001587)	(0.000867)	(0.001900)
Edu	-8.032355***	-1.591675	-9.352485***	11.677080***	25.416490***	8.152192***
	(2.376815)	(2.992860)	(2.745302)	(2.780632)	(4.677694)	(2.580967)
Constant	-0.193354	3.225470	-7.164970***	-4.348495*	1.020386	4.442901*
	(2.066743)	(2.348420)	(2.159730)	(2.611746)	(2.034316)	(2.267314)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
N	3036	3036	3036	3036	3036	3036
R^2	0.6331	0.6073	0.5504	0.4396	0.5583	0.5577

Notes: Standard errors are reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

4.4 Heterogeneity Analysis

Considering that cities at different tiers differ significantly in economic foundations, innovation resource concentration, and digital infrastructure, the effect of digital inclusive finance on green technology innovation may be heterogeneous. Therefore, this paper divides the sample into first-tier, new first-tier, second-tier, third-tier, fourth-tier, and fifth-tier cities and estimates the regressions separately after including the control variables[8][9]. The results are reported in Table 5.

The results show that the coefficient of DFI is significantly positive in both first-tier and fifth-tier cities. For first-tier cities, the effect can be attributed to the high concentration of innovation resources, high-end talent, financial service systems, and digital infrastructure, which allows digital inclusive finance to be more effectively transformed into green innovation output by improving resource allocation efficiency and strengthening innovation support. For fifth-tier cities, where traditional financial supply is relatively insufficient and innovative entities face stronger financing constraints, the inclusive and low-threshold features of digital inclusive finance can more effectively compensate for the shortcomings of conventional financial services, thereby generating a stronger marginal promoting effect. By contrast, cities from the new first tier to the fourth tier are located in a transitional range. They neither possess the outstanding innovation absorption and transformation capacity of first-tier cities nor the large scope for improvement in financial inclusion observed in fifth-tier cities. As a result, the promoting effect of digital inclusive finance is not fully manifested in these city groups. This type of heterogeneity is also reported in recent city-level studies of digital finance and green innovation.

Table 5. Heterogeneity analysis by city tier.

Variable	(1) First-tier	(2) New first-tier	(3) Second-tier	(4) Third-tier	(5) Fourth-tier	(6) Fifth-tier
DFI	0.0348**	0.0077	-0.0041	0.0050	0.0025	0.0110***
	(0.0064)	(0.0054)	(0.0064)	(0.0043)	(0.0039)	(0.0041)
Constant	-20.5444*	-6.9666**	-0.1168	-3.2695	-0.4324	1.6049
	(8.1361)	(2.9376)	(3.5029)	(8.9636)	(5.5698)	(6.4492)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
N	44	165	330	748	880	869
R^2	0.9822	0.9492	0.8643	0.8333	0.7260	0.7200

Notes: Standard errors are reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

5 Conclusion and Implications

Research indicates that digital inclusive finance significantly promotes green technological innovation in cities, with a stronger impact on improving the quality of green technologies than on expanding their quantity; the level of economic development plays a partial mediating role in this process; the findings remain robust after controlling for municipalities directly under the central government, lagged explanatory variables, and substitute explanatory variables. Heterogeneity analysis reveals that the promotional effects are more pronounced in first-tier and fifth-tier cities.

Based on these findings, we recommend the following: First, continue to improve digital financial infrastructure and the inclusive financial service system to enhance access to financing for green innovation entities; second, promote the synergistic development of digital finance and the economy to channel more capital toward green, high-value-added industries[10]; and third, implement differentiated policies tailored to different city tiers—strengthening the exemplary role of first-tier cities and enhancing the compensatory function of digital finance in regions with insufficient financial supply—to better unleash the green innovation effects of digital inclusive finance.

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