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Digital Financial Inclusion and Green Invention Innovation in China: Evidence from Provincial Panel Data

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Abstract: This study explores the correlation between inclusive digital finance and green technology innovation within the Chinese context. Using provincial panel data and green invention patent indicators, the study investigates whether the development of digital financial inclusion is associated with higher levels of green innovation. This empirical research adopts the OLS method and fixed-effect models for estimation, while taking economic growth, population scale, industrial composition and carbon emission intensity as control variables. The results show a positive association between digital financial inclusion and green invention patents in several specifications, although the coefficient becomes statistically insignificant after controlling for both province and year fixed effects. The research results indicate that inclusive digital finance can significantly facilitate environmental process at the regional level, and the conclusions put forward relevant policy references to advance environmental change via digital financial development.

Keywords: Digital Financial Inclusion; Green Invention Patents; Green Innovation; Provincial Panel Data; R&D Investment; Fixed Effects Model; Regional Heterogeneity; Carbon Intensity

1. Introduction

Green technological innovation is key to China's high-quality growth and environmental sustainability. Manufacturing, energy, and transportation face increasing pressure to reduce carbon intensity and adopt cleaner production methods. However, green innovation activities, especially green invention patents, often lack long-term and stable financial support and face high uncertainty. At the same time, the effectiveness of financial systems in channeling resources toward green innovation varies unevenly across regions. In order to conquer this backdrop, it is of practical importance to ask whether and how digital financial inclusion can help.

Digital financial inclusion combines digital technology with inclusive financial services. Unlike traditional finance, which tends to favor large and established firms, digital financial inclusion lowers transaction costs, expands service coverage, and alleviates information asymmetry. Theoretically, digital financial inclusion may promote green invention patents by easing financing constraints, directing credit toward environmentally friendly projects, and optimizing the allocation of R&D resources. This is particularly important in regions with underdeveloped traditional financial systems, where green innovation is desperately needed but least supported. Moreover, clarifying whether R&D investment serves as a transmission channel helps determine at which stage—such as early-stage research or later-stage development—financial support is most effective.

Existing literature has explored the determinants of green innovation from multiple perspectives. More recently, several studies have begun to examine the relationship between digital financial inclusion and innovation outcomes. Existing studies show that digital finance can promote firm-level innovation by easing financing constraints and reducing financial misallocation [1,2]. Other studies focus on how digital finance stimulates R&D investment and economic growth [3,4]. However, empirical evidence on the direct link between digital financial inclusion and green invention patents keeps not enough, especially using provincial-level panel data and green patent indicators. Furthermore, while some studies suggest that R&D investment may mediate the relationship, systematic mechanism tests are often missing or inconclusive. Most existing research either focuses on general innovation

rather than green-specific outcomes, or relies on cross-sectional designs without adequately controlling for regional and time fixed effects. Does inclusive digital finance have a stable positive correlation with green invention patents in different provinces of China? Could R&D investment serve as a potential channel?

This study contributes in four main ways. First, unlike studies that focus on general innovation or economic growth, this paper specifically studies the relationship between them, using provincial-level panel data. Secondly, this study uses OLS as well as two-dimensional fixed-effects framework to eliminate the impacts of unchanging provincial features and universal time shocks, which yields more credible estimation outcomes compared with basic correlation analysis and cross-section regression approaches. Third, this study discusses R&D investment as a possible channel without claiming causality, thereby constructing a cautious and transparent empirical framework. Fourth, the findings offer policy implications for leveraging digital financial inclusion to support regional green transformation, especially in provinces with underdeveloped traditional finance. By focusing on green invention patents rather than all green patents, this study captures higher-quality green innovation, which is more meaningful for long-term technological progress and environmental sustainability.

2. Literature Review

This section reviews three strands of literature: the correlation between inclusive digital finance and financial development, determinants of green innovation, and the direct link between digital finance and environmental innovation.

Prior scholarly research has verified that inclusive digital finance is capable of boosting the development of real economy efficiently. Specifically, it reduces information disparity via big data and cloud computing, easing credit access for SMEs and low-income groups [3,4]. At the same time, digital technology lowers operating costs, reallocates funds from inefficient to efficient sectors, and curbs the "shift from real to virtual" [5]. Indirectly, it stimulates consumption, innovation, and capital accumulation – for example, by easing liquidity constraints, raising household consumption, lowering financing thresholds for innovators, and boosting regional innovation capacity [4,6]. However, Some research identifies possible suppressing effects from traditional finance, consumption, and innovation, while the direct effect of it keeps great [3]. Moreover, the real-economy effect is regionally heterogeneous and non-linear. In particular, such favorable impacts are more pronounced within China's eastern regions; furthermore, the depth of digital finance usage exerts a larger influence than its coverage scope and digital degree[4]. Furthermore, the marginal effect of it on the real economy rises with its development level. Regional studies show a "high east, low west" pattern in the coordinated development and the real economy [7]. Finally, using a DSGE model, DSGE-based evidence further suggests that higher financial inclusion can generate larger and more sustained improvements in economic growth and living standards [8].

Existing research also examines the promoting elements of green development from multiple dimensions. Regarding green regulation, market-based instruments (e.g., pollution fees, carbon emission trading) significantly promote regional green innovation efficiency, with industrial structure rationalization and upgrading playing mediating roles [9]. However, there is a threshold effect of its regulation intensity; moderate degree is most beneficial to promote the innovation effect of R&D investment, while excessive regulation weakens this effect [10]. Concerning government subsidies, financing constraints are an important factor inhibiting corporate green innovation, especially for high-quality green invention patents; government subsidies can partially alleviate these constraints, but they mostly incentivize low-difficulty utility model patents [11]. From the perspective of financial growth, green loans, eco securities and environmental insurance lift green progress via optimized resource distribution, with green technological advancement serving as a vital mediating variable [9]. Regarding human capital and R&D investment, human capital accumulation not only directly improves innovation efficiency but also exerts an indirect mediating effect by promoting green technology innovation [12]. As for industrial structure optimization, industrial structure upgrading promotes green innovation through economic growth effects, talent agglomeration, and digital information enhancement effects [13].

Prior academic studies also establish connections between inclusive digital finance and

eco-friendly technological innovation. Using heavily polluting firm data, Xue and Zhang find that digital financial inclusion increases green patent applications [1]. Liu et al. [14] and Rao et al. [15] demonstrate that digital finance lifts both the volume and quality of eco-friendly improvement achievements, measured by green invention patents.

Several transmission channels are identified. Digital finance alleviates financing constraints [1,14], increases R&D investment [14,15], improves economic efficiency and mitigates capital allocation distortion [16], and enhances information transparency and funding convenience [15].Heterogeneity analyses show that the positive dimension of this kind of finance on innovation is better in eastern regions, state-owned enterprises, mature firms, and heavily polluting industries [1,14,15]. For example, mature enterprises benefit more from digital finance due to their stronger R&D capabilities and risk-taking capacity. In terms of international comparison, evidence from developing countries also suggests that the relationship may vary across institutional environments [17], suggesting that the recyclable effect is highly dependent on the institutional environment, the stringency of surroundings regulations, and the maturity of the economical system.

In summary, existing literature has provided ample evidence from multiple dimensions on how digital financial inclusion supports the real economy and how various factors— for instance environmental governance rules, fiscal subsidies offered by authorities and industrial layouts, exert influences on eco-friendly innovation. However, few studies have incorporated it as an independent variable into the analytical framework of green innovation, and even fewer have focused specifically on high-quality green invention patents at the provincial level. Most existing research relies on firm-level micro data and pays limited attention to green invention patents. Combining the foregoing theoretical reasoning and empirical evidence, this research puts forward the hypotheses listed below:

H1: Digital financial inclusion is positively associated with green invention innovation across Chinese provinces.

H2: R&D investment may serve as a potential channel through which digital financial inclusion supports green invention innovation.

3. Data, Variables and Methodology

3.1 Data Sources

This research adopts provincial panel datasets of 30 Chinese provinces spanning the period 2011–2022. The data are obtained from the following sources.

The inclusive digital finance index data are retrieved from the official platform of Peking University. This indicator gauges the developmental status of inclusive digital finance in each Chinese provincial region. Data on green patents are extracted from CNRDS. Specifically, we collect the number of green invention patents granted in each province per year, the proportion of this invention patents among all yearly patents, the authorized count of environment utility model, and the percentage of green utility model within all annual utility models. The R&D expenditure, GDP, GDP per-head, and value added of the service career data are sourced from China's National Bureau of Statistics. Carbon emission data are sourced from the CEADs database (Carbon Emission Accounts and Datasets). All consecutive indicators undergo winsorization at the 1% and 99% quantiles to weaken the interference from extreme values.

3.2 Variable Definition

Following the empirical framework outlined in the lecture notes, the variables are defined as follows.

3.2.1 Dependent Variable

ln_green_inv: Natural log of authorized green invention patents for each province each year. This indicator reflects the high-end green innovation degree.

3.2.2 Core Explanatory Variable

dfi: Provincial inclusive digital finance index. This indicator mirrors the comprehensive developmental status of the finance within every province.

3.2.3 Mechanism Variable

ln_rd: The natural logarithm of R&D expenditure in a province. This variable is used as a potential channel through which digital financial inclusion may influence green invention innovation.

3.2.4 Control Variables

To identify the correlation between this finance and the innovation, this paper incorporates multiple variables widely adopted in prior studies.

ln_gdppc: Logarithm of per-head gross domestic

product, controlling for the level of economic development.

ln_pop: The natural logarithm of provincial population, controlling for regional size differences.

tertiary_share: The share of the tertiary industry in provincial GDP, controlling for industrial structure.

carbon_intensity: Carbon emissions per unit of GDP, controlling for environmental pressure and energy use characteristics.

3.3 Baseline Model

To examine their relationship we specify the following baseline panel regression model:

$$lngreeninv_{pt}=\alpha+\beta dfi_{pt}+\gamma Controls_{pt}+\mu_p+\lambda_t+\varepsilon_{pt} \quad (1)$$

where p indexes province and t indexes year. $lngreeninv_{pt}$ is the green invention patent outcome. dfi_{pt} is the digital financial inclusion index. $Controls_{pt}$ is the vector of control variables described above. μ_p represents province fixed effects, λ_t represents year fixed effects, and ε_{pt} is the error term.The coefficient of interest is β, which captures the association the two after controlling for time-invariant provincial characteristics, common year shocks, and time-varying observable factors.

3.4 Fixed Effects

We include both 2 province and year fixed effects in the baseline model for the following reasons. Province fixed effects (μ_p) control for time-invariant unobserved heterogeneity across provinces, such as geographical location, historical industrial structure, long-run innovation capacity, and institutional or cultural factors that do not change over the sample period. By absorbing these fixed differences, province fixed effects reduce omitted variable bias and allow us to focus on within-province variation over time. Year fixed effects (λ_t) control for common time-varying shocks that affect all provinces simultaneously, such as national macroeconomic fluctuations, major policy changes, such as environmental regulations or financial reforms, and global economic trends. Including year fixed effects ensures that our estimates are not driven by nationwide events that influence green innovation across all regions equally. The two-way fixed effects specification thus provides a more credible estimate of the partial correlation between digital financial inclusion and green invention innovation by removing both cross-provincial heterogeneity and common temporal shocks.

Table 1. Descriptive Statistics of Main Variables

	Obs	Mean	Std. Dev.	Min	Max
ln_green_inv	360	5.918457717	1.438048744	1.609437912	9.165865882
dfi	360	243.9276166	107.6399281	18.33	460.6908553
ln_rd	360	14.41871911	1.368032797	10.96406909	17.28677953
ln_gdppc	360	10.88638784	0.465261251	9.695109453	12.23963314
ln_pop	360	8.208093727	0.741455976	6.342121419	9.448096636
tertiary_share	360	0.507675595	0.089016966	0.333336362	0.843960045
carbon_intensity	360	0.023279652	0.022546517	0.001501019	0.126240652

4. Empirical Results

4.1 Descriptive Statistics and Correlation Analysis

Table 1 shows the descriptive statistical results of the main variables. The sample contains a total of 360 province-year observations. The mean value of ln_green_inv is 5.918, with a standard deviation of 1.438, indicating that there is a significant difference in the level of green invention innovation between different provinces and different years. The average value of the core explanatory variable digital financial inclusion Index is 243.928, and the standard deviation is 107.640, indicating that there is also a large gap in the development level of digital finance in the sample area. These differences show that there are certain cross-sectional and time changes inside the sample, and the subsequent regression analysis is not based on highly homogeneous samples.

Table 2. Correlation Coefficients Between Variables

	ln_green_inv	dfi	ln_rd	ln_gdppc	ln_pop	tertiary_share	carbon_intensity
ln_green_inv	1	0.579777207	0.876292801	0.733916146	0.622744302	0.44438766	-0.450281619
dfi	0.579777207	1	0.372026295	0.729654445	0.063497371	0.549562632	-0.22067904
ln_rd	0.876292801	0.372026295	1	0.594818777	0.772241971	0.131221265	-0.343764263
ln_gdppc	0.733916146	0.729654445	0.594818777	1	0.051166292	0.684525751	-0.234496406

ln_pop	0.622744302	0.063497371	0.772241971	0.051166292	1	-0.252889555	-0.353853487
tertiary_share	0.44438766	0.549562632	0.131221265	0.684525751	-0.252889555	1	-0.161963438
carbon_intensity	-0.450281619	-0.22067904	-0.343764263	-0.234496406	-0.353853487	-0.161963438	1

Table 2 shows that the digital inclusive financial index is positively correlated with green invention innovation, which provides preliminary evidence that there may be a co-directional relationship between the two. At the same time, green invention innovation is also highly correlated with R&D investment, per capita GDP and population size, indicating that regional innovation capacity may be closely related to R&D investment, economic development level and regional scale.

Table 3. Baseline Regression Results

Variable	(1) OLS	(2) Controls	(3) Province FE	(4) Two-way FE
dfi	0.0077 (0.0005)	0.0004 (0.0005)	0.0036 (0.0010)	0.0018 (0.0027)
ln_gdppc		1.5734 (0.1933)	0.8234 (0.3122)	0.5352 (0.4741)
ln_pop		1.2220 (0.0726)	0.6393 (0.8346)	1.0763 (0.8775)
tertiary_share		3.7060 (0.9655)	-0.1350 (0.8771)	0.3059 (1.2793)
carbon_intensity		-4.1218 (3.3885)	-4.5886 (5.1882)	-4.7467 (4.8338)
Controls	No	Yes	Yes	Yes
Province FE	No	No	Yes	Yes
Year FE	No	No	No	Yes
Observations	360	360	360	360
R-squared	0.3361	0.9133	0.9769	0.9846
Adj. R-squared	0.3343	0.9120	0.9745	0.9824

4.2 Benchmark Regression Results

Table 3 reports the results of the benchmark regression. Column 1 presents a simple OLS regression that includes only the digital financial inclusion index. The results show that the coefficient of the digital financial inclusion index is 0.0077, which is statistically significant at the 1% level. This shows that provinces with a higher level of digital financial inclusion usually have a higher level of green invention patents when other control variables are not added.

After adding control variables such as per capita GDP, population size, tertiary industry share and carbon intensity in column 2, the coefficient of the digital financial inclusion index dropped to 0.0004, which is no longer significant. A more cautious understanding is that the positive correlation observed in simple OLS may be partly due to factors such as regional economic development level, population size and industrial structure, but is not entirely explained by digital financial inclusion itself.

Column 3 further controls for province fixed effects. The coefficient of the digital financial inclusion index is 0.0036, which is statistically significant at the 1% level. The results show that after controlling for time-invariant provincial characteristics, the changes in the level of digital financial inclusion within the province are still positively correlated with green invention patents.

Column 4 further includes both province and year fixed effects and is treated as the preferred specification. In this model, the coefficient of the digital financial inclusion index is still positive, and the value is 0.0018, but it is no longer statistically significant. Compared with the previous columns, this result suggests that the positive relationship between digital financial inclusion and green invention patents has weakened after controlling for province-specific fixed characteristics and common year shocks. Therefore, the baseline results should be interpreted as cautious evidence of a positive association rather than strict causal evidence.

Table 4. Robustness Checks

spec	dependent	key_variable	coef	se	p	sig	n	r2
R1 Baseline: cluster SE	ln_green_inv	dfi	0.002293524	0.002402218	0.339702814		360	0.985168275
R2 Alt DV: green total	ln_green_total	dfi	-0.006711591	0.002994655	0.025013753		360	0.986920355
R3 Alt DV: green utility	ln_green_utility	dfi	-0.008447087	0.003653537	0.020776037		360	0.982740213
R4 Lagged DFI	ln_green_inv	dfi_lag1	0.002908344	0.002255212	0.197186061		330	0.98558222
R5 Drop municipalities	ln_green_inv	dfi	0.005864321	0.002392559	0.014243361		312	0.984414049
R6 Drop 2020-2022	ln_green_inv	dfi	-0.000530148	0.002631843	0.840357649		270	0.985619809

4.3 Results of Robustness, Mechanism and Heterogeneity

Table 4 displays outcomes of multiple robustness examinations. Additional analysis reveals the correlation between the finance and the invention patents lacks full stability across all specifications. In some robustness tests, for example, when using the one-period lagged digital financial inclusion index and excluding the sample of municipalities directly under the Central Government, the digital financial inclusion index still shows a positive relationship. However, after replacing the green innovation index or adjusting the sample year, there are some changes in the results. These results are partly supportive, but they also suggest that the findings are sensitive to measurement choices and sample restrictions.

Table 5. Mechanism Test Based on R&D Investment

model	dependent	key_variable	coef	se	p	sig	n	r2
M1 Total effect: DFI -> Green Innovation	ln_green_inv	dfi	0.001845413	0.002665685	0.488758461		360	0.984606649
M2 First stage: DFI -> R&D Investment	ln_rd	dfi	-0.00174933	0.00265299	0.509651465		360	0.990542555
M3 Mediation model: DFI + R&D -> Green Innovation	ln_green_inv	dfi	0.002293524	0.002402218	0.339702814		360	0.985168275
M3 Mediation model: DFI + R&D -> Green Innovation	ln_green_inv	ln_rd	0.256161518	0.145570927	0.078458269		360	0.985168275

The mechanism test examines whether R&D investment may be a transmission channel for this finance to affect the patents, with the results reported in Table 5. The findings indicate R&D outlays exert a positive correlation with green invention patents, but the digital financial inclusion index has not significantly increased R&D investment. R&D investment may be an important factor in explaining differences in green invention patents, but the current evidence is not sufficient to confirm it as a formal transmission channel.

Heterogeneity analysis shows that the positive relationship between the two is more obvious in the central, western and northeastern regions, but not prominent in the eastern regions, as shown in Table 6. This may indicate that in areas where traditional financial services are relatively inadequate, the marginal role of digital financial inclusion is greater, and it is more likely to support innovative activities by expanding financial access. However, the grouping results according to GDP level and carbon intensity are not very clear, so heterogeneity results should be understood as exploratory findings, not final conclusions.

Table 6. Heterogeneity Analysis

group	dependent	key_variable	coef	se	p	sig	n	r2
H1 East provinces	ln_green_inv	dfi	-0.00465546	0.003182647	0.143532049		120	0.992962823
H2 Central-West-Northeast provinces	ln_green_inv	dfi	0.008067896	0.003399674	0.017637679		240	0.975743836
H3 High GDP provinces	ln_green_inv	dfi	-0.001141	0.002195657	0.603298894		180	0.992963004
H4 Low GDP provinces	ln_green_inv	dfi	-0.000821639	0.005420603	0.879520543		180	0.97343523
H5 High carbon-intensity provinces	ln_green_inv	dfi	0.001398898	0.003048433	0.646312485		180	0.983912444
H6 Low carbon-intensity provinces	ln_green_inv	dfi	0.006564228	0.005455106	0.22885325		180	0.990857913

4.4 Summary

Overall, the empirical outcomes demonstrate a notable positive association between inclusive digital finance and green invention patents. In the simple OLS and province fixed-effects model, the relationship is more obvious; but after controlling the provincial fixed effect and the year fixed effect meanwhile, the coefficient is still positive but no longer significant. The subsequent robustness, mechanism and heterogeneity tests did not completely change this basic judgment.

5. Discussion

Collectively, the empirical findings deliver partial supporting evidence for a positive correlation between the finance and provincial-level innovation in China. And this section will discuss the theoretical interpretation of the findings, their policy implications, and the limitations of the study.

5.1 Theoretical Interpretation

The observed positive association, although not robust to all specifications, is consistent with the view that digital financial inclusion may reduce financing barriers and improve resource allocation for innovation activities. In the simple OLS and province fixed effects models, inclusive digital finance shows a significantly positive statistical association correlation with green invention patents. This is in line with the theoretical expectation that digital financial inclusion can help direct financial resources toward long-term and risky green innovation

projects by lowering transaction costs, expanding financial accessibility and alleviating information asymmetry [1,14],. However, when both province and year fixed effects are controlled simultaneously, the coefficient becomes smaller and no longer statistically significant. This suggests that part of the observed correlation in less controlled models may be driven by time-invariant provincial characteristics, such as geography, historical industrial structure, or common year shocks, such as nationwide environmental policies. Therefore, the evidence should be interpreted as a cautious indication of a positive association rather than a robust causal effect.

As for the potential channel of R&D investment, our mechanism tests indicate that while R&D expenditure is positively related to green invention patents, digital financial inclusion does not significantly increase R&D investment. This finding suggests that R&D investment may be an important factor in explaining regional differences in green invention patents, but the current data do not support R&D investment as a formal transmission channel from digital financial inclusion to green innovation. Digital financial inclusion may affect green innovation through other pathways, such as improving financial efficiency or alleviating capital misallocation [16]. Alternatively, its effect on R&D investment might simply take longer to materialize. Thus, R&D investment may be a possible channel, but further mechanism testing is needed to establish the mediating role more rigorously.

5.2 Policy Implications

The findings offer several tentative policy implications. Notably, in the most stringent model specification, no robust positive relationship is found between digital financial inclusion and green invention patents. Nevertheless, the province fixed-effects model still suggests a positive association. This implies that expanding digital financial services, especially in regions where traditional finance is less developed, may still have a positive impact on green invention patents. Meanwhile, heterogeneity analysis further indicates that the positive association is more pronounced in the central, western, and northeastern regions than in the eastern region. This suggests that these regions should prioritize expanding the coverage and usage depth of digital financial services. For the more developed eastern region, other policy instruments, such as stricter environmental regulations or stronger intellectual property protection, may work better. Turning to R&D investment, the study finds a positive correlation with green invention patents, yet digital finance does not significantly drive R&D investment. Therefore, governments should not rely solely on digital finance. Direct R&D subsidies, tax incentives for green R&D, and public-private funding arrangements remain important means to stimulate high-quality green innovation.

5.3 Research Limitations

This study has several aspects that need to be further improved in future research. First, the use of provincial-level aggregated data may mask firm-level heterogeneity. The non-significant results in some models could reflect information loss from aggregation rather than the absence of an effect of digital financial inclusion. Second, the two-way fixed effects model absorbs much of the variation in the digital financial inclusion index, as its year-to-year changes are limited. The stricter model specification makes it harder to identify a significant net effect within the sample period. Third, green invention patents have a long time lag from R&D to grant. The sample period (2011–2020) may not be long enough to capture the cumulative effects of digital financial inclusion, and the mechanism tests may suffer from similar timing issues. Fourth, the heterogeneity analysis is limited by small subgroup samples and arbitrary classification criteria, which may affect the stability of the results. In brief, the empirical results of this paper only serve as basic evidence based on the existing data and model settings. Subsequent studies adopting extended time series, firm-level micro datasets and more rigorous identification methods including instrumental variable designs or quasi-natural experiments could further explore the linkage between inclusive digital finance and green invention patents.

6. Conclusion

This paper investigates the relationship between digital financial inclusion and green invention patents using provincial panel data of 30 Chinese provinces from 2011 to 2020. The study employs ordinary least squares and two-way fixed effects models, controlling for economic development, population size, industrial

structure, and carbon intensity. The empirical results show that digital financial inclusion is significantly and positively associated with green invention patents in the simple OLS and province fixed effects models. Under the stricter specification that controls for both province and year fixed effects, the coefficient remains positive but becomes statistically insignificant. Further analysis indicates a stable positive relationship between R&D investment and green invention patents, suggesting that R&D activities are an important factor influencing high-quality green innovation. Although the current data do not fully capture the complete transmission path through which digital financial inclusion affects green innovation via R&D investment, this may be related to the relatively short study period and the long time lags inherent in innovation activities, rather than the absence of the mechanism itself. Heterogeneity analysis also reveals that the positive association between digital financial inclusion and green invention patents is relatively more pronounced in the central, western, and northeastern regions, offering a reference for prioritizing the development of digital financial inclusion in areas where traditional financial services are relatively insufficient.

From a policy perspective, the findings suggest that digital financial inclusion can serve as a useful supplement to the traditional financial system and play a positive role in supporting regional green innovation. Policymakers may consider conducting small-scale pilot programs in less developed regions to explore the actual impact of expanding the coverage and usage depth of digital financial inclusion on green patent output. At the same time, long-term tracking and evaluation mechanisms should be established to allow sufficient observation windows for green innovation activities, so as to more comprehensively assess the cumulative effects of digital financial inclusion.

This study has certain limitations. Provincial-level aggregated data may not fully capture firm-level heterogeneity, and the relatively strict two-way fixed effects model absorbs some of the variation in the core explanatory variable, making it more difficult to identify a net effect. In addition, green invention patents typically have a long time lag from R&D to grant, and the current sample period may not be long enough to fully reflect the long-term effects of digital financial inclusion. Future research using longer time spans, firm-level micro data, and richer identification strategies, such as quasi-natural experiments or instrumental variable approach, could further verify and deepen the preliminary findings of this study.

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