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Research on the Impact of Digital Finance on Energy Efficiency in China

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Abstract: Digital finance and green technology innovation (GTI) serve as powerful engines for promoting energy efficiency (EE) and economic development. This paper explores the mechanism by which digital finance impacts EE based on panel data from 30 provinces in China spanning from 2011 to 2019. The results demonstrate that digital finance can significantly enhance EE, with a particularly pronounced effect in the eastern region. Through mechanistic analysis, it is evident that GTI serves as the transmission pathway through which digital finance influences EE, accounting for 45.3% of the effect. The policy implication of this study suggests that China should expedite the digitization of financial markets to further harness the development of digital finance, particularly in pursuit of its technological innovation and green, low-carbon environmental protection effects.

Keywords: Digital finance; Green technology innovation; Energy efficiency

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1. Introduction

The energy industry holds strategic significance, yet the increasing tension between economic growth and environmental protection poses a challenge in balancing energy supply with low-carbon energy transformation for achieving high-quality energy development. China's 14th Five-Year Plan for a modern energy system explicitly outlines the need to accelerate technological advancements and equipment development in the energy sector, emphasizing major breakthroughs in green and low-carbon technologies as essential components of building a modern energy system. The Communist Party of China's 14th Five-Year Plan underscores the importance of expediting the development of a green, low-carbon circular economy and advancing green development objectives such as carbon peaking and neutrality, thereby enhancing energy and resource utilization efficiency.

Energy efficiency (EE), defined as achieving the same output with less energy input, primarily improves through technological progress [1]. Technological innovation with a focus on green initiatives plays a crucial role in enhancing EE. Green technology innovation (GTI) possesses environmentally friendly attributes crucial for the transformation of the energy-economic system. However, GTI's innovation endeavors often encounter significant financing constraints due to high investment costs, lengthy investment cycles, and huge

income risks. In recent years, digital finance has rapidly evolved, with data serving as a core production factor embodying both technological and green attributes. As a novel financial model integrating digital infrastructure with traditional finance, digital finance boasts essential characteristics such as low service cost, wide service range, and high service efficiency, playing a vital role in alleviating financing constraints faced by innovative and green enterprises [2]. Nevertheless, systematic studies on the influence of digital finance on EE are lacking, which this study aims to address.

Given the relatively limited existing research on the impact of digital finance on EE, particularly concerning its interaction with GTI, there remains a gap in understanding the mechanisms by which digital finance affects EE. To bridge this gap, panel data from 30 Chinese provinces spanning from 2011 to 2019 were utilized to conduct an empirical study investigating the influence of digital finance on EE. This paper contributes in two main ways: firstly, the impact of digital finance on EE considering regional heterogeneity was examined using a panel fixed-effect model; secondly, from the perspective of GTI, whether digital finance supports corporate GTI to enhance EE was investigated. The subsequent sections of the paper are organized as follows: Section 2 presents the literature review and research hypotheses; Section 3 outlines the methodology and data sources; Section 4 discusses the empirical findings; and Section 5 summarizes the conclusions and implications derived from the study.

2. Literature review and research hypotheses

The financial system plays a crucial role in optimizing resource allocation, which is vital for achieving low carbon emissions and sustainable development. However, scholars have not yet reached a consensus regarding the impact of financial development on energy and the environment. Some argue that financial development stimulates investment activities, consumption, and economic growth, consequently leading to increased energy demand and pollution emissions [3]. For instance, Fang *et al*. asserted that while financial development has promoted China's economy, it has also resulted in higher CO_2 emissions [4]. Conversely, others hold the opposite view, suggesting that financial development reduces energy waste and pollution emissions. For example, Umar *et al*. found that financial development can effectively promote technological progress and industrial upgrading, thereby improving EE [5].

As a novel financial model, digital finance may emerge as a key factor in addressing the dilemma of increasing energy demand and ensuring sufficient energy supply. Firstly, research indicates that digital finance can effectively address the limitations of traditional finance by bridging the capital supply gap arising from information asymmetry between fund suppliers and demanders. This inclusion of a broader spectrum of participants in the financial market, including small-scale investors, enhances the availability of green loans [6], consequently reducing enterprise financing costs and alleviating financing constraints. The expanded funding sources enable financial sectors to relax constraints on GTI [7]. Moreover, digital finance can provide both technical and financial support for sustainable development, catering to the green transmission needs of enterprises [8]. Additionally, digital finance diversifies risks that conventional financial institutions may be unwilling to undertake, thereby providing a foundation for spreading innovation risks across a broader community. With the advancement of digital finance, GTI has received significant financial support, potentially leading to increased EE [9].

Based on the above, the following research hypotheses are proposed:

(1) H_1: The development of digital finance contributes to enhancing EE.

(2) H_2: The positive impact of digital finance on EE is attributable to GTI.

3. Methodology and data

3.1. Panel bidirectional fixed effect model

To examine the impact of digital finance on EE, the following regression model was constructed:

$$EE_{it} = \alpha_0 + \alpha_1 DFI_{it} + \sum_k \alpha_2 Controls_{k,it} + \varphi_i + \eta_t + \varepsilon_{it} \quad (1)$$

where *i* and *t* denote the province and year; *EE* is energy efficiency; *DFI* represents the development of digital finance. In addition, a series of control variables are considered to capture provincial characteristics that may affect the EE level. φ_i and η_t are the individual fixed effect and time fixed effect, while ε_{it} is the error term.

3.2. Mediating effect model

To test the impact mechanism and transmission path between digital finance and EE, the following methods described by Gomber *et al*. were utilized to establish a mediating effect model [10]:

$$GTI_{it} = \beta_0 + \beta_1 DFI_{it} + \sum_k \beta_2 Controls_{k,it} + \varphi_i + \eta_t + \varepsilon_{it} \quad (2)$$

$$EE_{it} = \gamma_0 + \gamma_1 DFI_{it} + \gamma_2 GTI_{it} + \sum_k \gamma_3 Controls_{k,it} + \varphi_i + \eta_t + \varepsilon_{it} \quad (3)$$

3.3. Variable selection

The dependent variable (EE) is measured as the ratio of actual GDP (based on 2011) to total energy consumption. The explanatory variable (DFI) is measured using the Digital Finance Index released by Peking University, which utilizes extensive digital finance data as the measurement basis and constructs a comprehensive evaluation index for digital finance development. To standardize the index across dimensions, each province's index is divided by 100.

Control variables include the following:

(1) Industrial structure (Is): Measured as the ratio of the added value of the secondary industry to the added value of the tertiary industry, serving as an indicator of industrial structure.

(2) Human capital (Hc): Measured by average years of schooling.

(3) Environmental regulation index (Eri): Calculated using the entropy method, considering factors such as industrial wastewater discharge, general industrial solid waste production, and industrial sulfur dioxide discharge.

(4) Rate of technology transfer (Lnrtt): Represented by the logarithm of technology contract transactions to reflect the conversion rate of technological achievements

(5) Foreign direct investment (Lnfdi): Represented by the logarithm of per capita FDI amount, compared with the nominal value of each region for the current year.

Mediating variables (GTI) are measured as the ratio of green patent applications in each region to the resident population.

3.4. Data and variables

This study utilizes panel data from 30 provinces, excluding the regions of Hong Kong, Macao, and Taiwan, as well as the Tibet Autonomous Region, spanning from 2011 to 2019 for empirical analysis. Energy consumption data is sourced from the China Energy Statistical Yearbook, while the digital finance index is obtained from the Peking University Digital Finance Index. The number of green patent applications is retrieved from the China

Research Data Service Platform. Other variable data is sourced from the National Bureau of Statistics website, the China Statistical Yearbook, and statistical yearbooks of various provinces. Descriptive statistics for the variables are presented in **Table 1**.

Table 1. Descriptive statistics

Variables	Variables description	Obs	Mean	SD	Min	Max
EE	Energy efficiency	270	1.520	0.707	0.436	4.021
DFI	Digital finance index	270	2.027	0.920	0.183	4.103
Is	Industrial structure	270	0.899	0.283	0.191	1.897
Hc	Human capital	270	9.172	0.893	7.470	12.780
Eri	Environmental regulation index	270	0.762	0.162	0.268	0.998
Lnrtt	Rate of technology transfer	270	13.837	1.762	8.642	17.810
Lnfdi	Foreign direct investment	270	14.760	1.749	7.880	17.610
GTI	Green technology innovation	270	0.896	1.442	0.023	10.972

4. Empirical results and analysis

4.1. Relationship between digital finance and EE

4.1.1. Regression results

Table 2 presents the econometric findings of the fixed effects panel model. Columns (1) and (2) display results with and without control variables, respectively. In both cases, a statistically significant positive relationship is observed at the 1% level, indicating that the development of digital finance significantly enhances EE. This suggests that digital finance can boost EE by expanding capital scale and diversifying risks. Thus, Hypothesis 1 is supported.

4.1.2. Heterogeneity analysis

Considering the variations in resource endowment and development intensity across different regions in China, the total sample was divided into three sub-samples based on the eastern, central, and western regions for regional heterogeneity analysis. The empirical results are presented in **Table 2**, columns (3), (4), and (5). In the eastern and central regions, the coefficient of digital finance development is significantly positive at the 1% level, whereas in the western region, it is significant at the 10% level. Furthermore, the coefficient is largest in the eastern region, followed by the central region, with the western region exhibiting the smallest coefficient. This discrepancy can be attributed to the earlier development of digital finance in the eastern region, leading to more proficient digital finance practices. Consequently, the eastern region is better positioned to leverage the capabilities of digital finance in alleviating financing constraints and resource mismatches, thereby significantly improving EE. However, in the central and western regions, where financial resources are relatively scarce and industrial development is lower, the inadequate supply of digital infrastructure hampers the impact of digital finance on EE.

4.2. Impact mechanism and transmission path

Table 3 presents the estimated results. The benchmark regression results in column (1) indicate that the development of digital finance significantly enhances EE. In column (2), the coefficient of digital finance development is also significantly positive, suggesting a substantial promoting effect on GTI. Upon adding intermediary variables to the benchmark regression model, as shown in column (3), the coefficient of GTI in the intermediary variable is significantly positive at 0.121. Furthermore, the coefficient of digital finance

development in column (3) decreases to 0.405 compared to the total effect of 0.738 in column (1). This suggests that GTI plays a partial mediating role in the process of promoting EE through the development of digital finance, with the mediating effect accounting for 45.3% of the total effect. These findings indicate that the development of digital finance fosters improvements in EE by enhancing GTI. Thus, Hypothesis 2 is supported.

Table 2. The results of the fixed effects panel model

Variables	EE				
	(1)	(2)	(3)	(4)	(5)
DFI	0.736*** (0.122)	0.738*** (0.121)	0.394* (0.236)	0.552*** (0.164)	0.831*** (0.166)
Is		0.164* (0.091)	0.068 (0.250)	0.547*** (0.086)	0.630*** (0.176)
Hc		0.110* (0.058)	0.090 (0.112)	0.003 (0.069)	0.048 (0.071)
Eri		0.078 (0.189)	0.311 (0.444)	0.936*** (0.225)	0.031 (0.246)
Lnrtt		0.060*** (0.019)	0.064* (0.034)	0.028 (0.031)	0.083*** (0.029)
Lnfdi		0.022 (0.019)	0.023 (0.039)	0.075*** (0.022)	0.094*** (0.030)
Constant	2.208*** (0.129)	0.596 (0.866)	0.009 (0.756)	0.606 (0.656)	1.197 (1.057)
Fixed year effect	Yes	Yes	Yes	Yes	Yes
Fixed province effect	Yes	Yes	Yes	Yes	Yes
Obs	270	270	99	72	99
R2	0.786	0.802	0.939	0.966	0.934

The values in parentheses are *t* values. ***, ** and * denote the significance levels of 1%, 5% and 10%, respectively.

Table 3. The impact mechanism of digital finance on EE

Variables	EE	GTI	EE
	(1)	(2)	(3)
DFI	0.738*** (0.121)	2.764*** (0.466)	0.405*** (0.115)
GTI			0.121*** (0.015)
Is	0.164* (0.091)	1.410*** (0.352)	0.006 (0.084)
Hc	0.110* (0.058)	0.831*** (0.225)	0.010 (0.053)
Eri	0.078 (0.189)	3.093*** (0.730)	0.451** (0.175)
Lnrtt	0.060*** (0.019)	0.056 (0.075)	0.066*** (0.017)
Lnfdi	0.022 (0.019)	0.153** (0.075)	0.003 (0.017)
Constant	0.596 (0.866)	5.780* (3.338)	0.100 (0.774)
Fixed year effect	Yes	Yes	Yes
Fixed province effect	Yes	Yes	Yes
Obs.	270	270	270
R2	0.802	0.571	0.845

The values in parentheses are *t* values. ***, ** and * denote the significance levels of 1%, 5% and 10%, respectively.

4.3. Robustness tests

To verify the reliability of the conclusions drawn in Section 4.2, the one-period-lagged mediating variable (L.GTI) was used to re-estimate formulas (2) and (3). **Table 4** presents the results, indicating that the coefficients remain significantly positive. These findings suggest that GTI continues to exert a partial mediating effect in the process of enhancing EE through the development of digital finance, with the mediating effect accounting for 50.1% of the total effect. Thus, the results obtained from the meditating effect model indicate that the empirical results remain largely consistent.

Table 4. The results of robustness tests

Variables	EE	L.GTI	EE
	(1)	(2)	(3)
DFI	0.738*** (0.121)	3.004*** (0.448)	0.367*** (0.118)
L.GTI			0.123*** (0.016)
Constant	0.596 (0.866)	-6.404** (3.209)	0.194 (0.779)
Controls	Yes	Yes	Yes
Fixed year effect	Yes	Yes	Yes
Fixed province effect	Yes	Yes	Yes
Obs.	270	270	270
R2	0.802	0.885	0.843

The values in parentheses are *t* values. ***, ** and * denote the significance levels of 1%, 5% and 10%, respectively.

5. Conclusion

China's energy and environmental challenges have garnered widespread attention from scholars. In recent years, digital finance has disrupted traditional finance across various domains. However, few scholars have examined the relationship between digital finance and EE. Drawing from existing literature, research hypotheses were formulated and a survey on the effects of digital finance on energy efficiency was conducted using provincial-level data from China spanning 2011 to 2019. The research indicates that the development of digital finance can significantly enhance EE, with GTI playing a mediating role in this process. This study offers clear implications for China to leverage the environmental benefits of digital finance and promote EE.

Based on the empirical findings, several meaningful inferences can be drawn. Firstly, the government should foster the development of digital finance and fully exploit its potential to promote sustainable energy development and environmental improvement. This entails strengthening infrastructure construction to expand the coverage of digital finance and enhance its service efficiency.

Secondly, the eastern region should prioritize enhancing green innovation incentives and adjusting energy structures to facilitate a green transformation in energy consumption. The central region should focus on enhancing digital finance capabilities and bolstering the construction of cooperative industrial clusters with significant knowledge advantages, thereby fostering greater environmental awareness. In the western region, efforts should concentrate on enhancing digital infrastructure completion and strategic talent planning to drive transformation and upgrade the energy economy structure with support from digital finance.

Thirdly, there is a need to optimize the environment for GTI and facilitate the efficient flow of innovative elements. Local governments can establish digital financial service platforms, create a robust financial support system for GTI, enhance financing incentives, and provide better financing and development guarantees

for enterprise GTI. Simultaneously, it is essential to dismantle local protectionist measures, accelerate the establishment of cross-regional innovation market integration mechanisms, and narrow the gap in green development capabilities between regions.

Disclosure statement

The author declares no conflict of interest.

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